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A Summary of the Current Research

Program 7/1/66 and Preliminary

Report of Progress for 7/1/65 to 6/30/66

FOREST SERVICE

of the

UNITED STATES DEPARTMENT OF AGRICULTURE

and related work of the

STATE AGRICULTURAL EXPERIMENT STATIONS

This research progress report is primarily a tool for use of scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs.

The summaries of progress on USDA and cooperative research include some tentative results that have not been tested sufficiently to justify general release. Such findings, when adequately confirmed, will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting results of USDA and cooperative research, and related State Agricultural Experiment Station research, issued between July 1, 1965, and June 30, 1966. This progress report was compiled in the Forest Service, U.S. Department of Agriculture, Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Washington, D.C.

July 1, 1966

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ROCKY MOUNTAIN STATION

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INTRODUCTION

This report summarizes progress during the past year in the forestry research program of the Department of Agriculture. Included is research carried on directly by Department scientists and that done cooperatively with other agencies. A summary of new information for each subject-matter area is followed by a list of pertinent publications. The report concludes with a tabulation of currently active research projects.

As a step toward implementation of the recommendations for a National Program of Research for Agriculture made jointly by the Association of State Universities and Land Grant Colleges and the USDA, a section has been added to each of the Areas in this report. It comprises a list of the related publications of the State Agricultural Experiment Stations in addition to those heretofore reported covering the results of USDA and cooperative research. In future years, it is anticipated that information will be available to permit reporting of achievements resulting from State research in a format comparable to the present reporting of the USDA and cooperative research.

The Department's research program provides the basis for management of the National Forests and National Grasslands by the Forest Service. It furnishes the technical base for protecting, developing, and utilizing the resources of forest and range lands administered by other Federal agencies. And it contributes in large measure to the fund of knowledge on which depends effective management of all the Nation's forest lands and the utilization of forest products.

The National Forestry Research Advisory Committee annually reviews the forestry research of the Department of Agriculture. Progress during the past year and plans for the year ahead are discussed. The aim is to concentrate available resources on the more pressing problems and at the same time maintain proper balance toward achieving long-range objectives. Coordination of research efforts receives attention.

Research undertaken directly by Department scientists is conducted at the national headquarters, Washington, D. C., at the Forest Products Laboratory, Madison, Wisconsin, at nine Regional Forest Experiment Stations which carry out projects at a number of locations throughout the United States, and at the Institute of Tropical Forestry in Puerto Rico. Most of the research is headquartered on or near the campuses of colleges and universities. There are 334 active projects requiring about 1,000 man-years of professional effort.

A total of 244 scientist man-years is devoted to forestry research at the State Experiment Stations and schools of forestry. This is exclusive of any research supported by McIntire-Stennis Program funds, but includes 63 scientist man-years of non-Federally supported research at the nine non-Land-Grant forestry schools which participate in the McIntire-Stennis Program.

Department research effort extends from the initial development of information to its application. Examples from the past year follow:

New reference book on important forest trees of the United States. The first comprehensive summary of pertinent information on the life histories of the major commercial forest tree species in this country has just been issued as USDA Handbook No. 271. This 762-page, illustrated book entitled "Silvics of Forest Trees of the United States" is a compilation of reports prepared by many Forest Service scientists in all parts of the country. Each of the 125 most important native forest trees of the United States is described in terms of its distribution and growth requirements. Included also are

details about seed production, natural regeneration, tree size at maturity, and known varieties and hybrids. Forest managers, students, and scientists consider the book a valuable reference and have nearly exhausted the initial printing of 16,000 copies.

Paper mill effluent used to irrigate pines. Three years of study in Louisiana show that paper mill effluent may safely be used to irrigate pines. If strong wastes are avoided, perhaps as much as 20 to 40 area inches of effluent can be disposed of in this way--benefitting trees and keeping a major source of pollution out of streams.

Warm nights make better seedlings. The temperature regime of the nursery can influence the vigor of ponderosa pine seedling root systems. In California, ponderosa pine transplants from a nursery with warm night temperatures produced more and longer roots than transplants from another nursery with cold night temperatures, although the day temperatures of the two nurseries were similar. A night temperature greater than 5° C. and averaging no more than 10° to 14° cooler than day temperatures seemed to yield the greatest root production. This day-night temperature difference may prove to be a valuable criterion in selecting nursery sites for ponderosa pine.

Jack pines differ in susceptibility to the needle cast fungus. At the end of the tenth growing season the least susceptible of 29 seed sources from northeastern Minnesota had only about 25 percent infection compared with 95 percent for trees from a Lower Michigan source. Since these differences remain constant from year to year and from environment to environment, they are likely to be genetically controlled. From these seed-source tests, selected trees will provide breeding material for geneticists to develop strains of jack pine resistant to the needle-cast fungus.

Breakthrough in snowpack measurement. A breakthrough in technique for measuring snow for predicting summer water supplies has been made in California. The new system may eliminate or greatly reduce the need for snow survey crews to make dangerous monthly treks into the mountains. A nuclear instrument that measures the depth and density of snow has been adapted to the needs of snow surveys. The measurements can be made without destroying the sampling site, as other methods do, so it can be sampled again and again. In addition, the motorized gage can be operated by radio from an office miles away, with the measurements also coming back by radio. It will be used in glacier research in Alaska, and snow research on the Continental Divide. As it can sense high rate of snowmelt from rain-on-snow storms, it will be invaluable in flood forecasting.

Boundary Waters Canoe Area--How can it be heavily used and its esthetic values maintained? Answer: Only through visitor understanding and cooperation. The problem of sustaining heavy use and maintaining esthetic values is in particularly sharp focus at Minnesota's Boundary Waters Canoe Area (BWCA). BWCA sustained 250,000 visits in 1965, and more are expected this year. The area's soils are thin and fragile. Even lightly used campsites have lost 50 to 99 percent of their ground cover. Tree reproduction on these sites is absent; erosion, compaction, and root exposure are prevalent.

Interviews with canoeists show that most of them have little or no knowledge of soil and plant capabilities, and do not realize they are unintentionally damaging the sites used for camping. Educational programs are needed. These should include the fundamentals of forest ecology and encourage dispersed use. In addition to Forest Service visitor information programs, there is a fine opportunity for assistance through the cooperation of the outfitters who rent canoes, tents, and supplies to recreation visitors. Most canoeists rely heavily on canoe outfitter pamphlets in

planning their trips, and an estimated two-thirds follow routes suggested by the outfitters. An organized routing plan could reduce site impacts and help bring about a better distribution of use.

Increased profits from improved grazing management of semidesert range. In Arizona, improved management through reducing intensity of use and changing from yearlong grazing to alternate-year summer deferment increased beef production by more than $1 per acre per year. Similar increases could be obtained by applying these practices to 6 million acres of high-potential semidesert range in Arizona alone. Most of this area has, in the past, been grazed on a yearlong basis with no provision for periodic rest to restore plant vigor.

Juniper-pinyon range restoration increases forage for deer and livestock. Closed stands of juniper-pinyon in Utah often produce less than 100 pounds of forage annually per acre. However, eradication of the trees and seeding desirable grasses, forbs, and shrubs on a 4,000-acre tract increased forage production to over 700 pounds per acre. Deer use in untreated juniper-pinyon stands averaged only 4 deer-days per acre as compared to 83 deer-days per acre on seeded stands--a 20-fold increase. Such treatment also benefits livestock because 4 acres of treated range will support one cow per month without undue interference with use by deer.

Watershed values are also greatly improved by juniper-pinyon range restoration. Ground cover averages 25 percent on untreated areas and 73 percent on seeded areas. Such restoration programs can be applied to 13 million acres in Utah alone.

Fewer lightning strokes come from seeded clouds. Recent pilot plant trials aimed at modifying lightning storms show that storms heavily seeded with silver iodide produced one-third fewer cloud-to-ground lightning strokes than do untreated storms. Success in lightning prevention depends on seeding particular cloud forms with specific amounts of silver iodide at just the right time. Development of operational techniques utilizing these research results may prevent 2,000 to 3,000 lightning fires annually.

Fire prevention studies have paid off. A fire prevention study in northern California has identified a small segment of the population that causes a disproportionately large number of fires. They are younger rural residents, both male and female, with part-time jobs, very little knowledge about the fire problem, and no strong feelings one way or the other about fire prevention. On the basis of these findings, the State of California is increasing its expenditures on fire prevention contacts with this high risk group and greatly reducing its expenditures on the other 90 percent of the population. The result will be a savings of $2 million annually and a potential increase in prevention effectiveness.

Bark beetle sex attractant synthesized. The sex attractant for the bark beetle Ips confusus, isolated and identified last year, has recently been synthesized in the laboratory. Researchers at the University of California and Stanford Research Institute, working together under Forest Service grants, successfully produced the material and have proved its attractiveness. The synthetic attractant is as effective in luring the beetles as is the natural material produced by the male beetles. This is a major step forward toward the time when it will be possible to attract destructive bark beetles into selected places where they may be sterilized, poisoned, or otherwise destroyed.

Parasites established to help control Dutch elm disease. Dutch elm disease, the most serious pest of American elms, is transmitted from infected to healthy trees by bark beetles. The only practical way to control the disease is to control the beetles. Insecticides are effective but they are expensive and some have undesirable side effects. Biological control is a potential solution in a situation of this kind, and a species of parasitic wasp was recently introduced from Europe for control of the beetles that spread the disease. The parasite appears to be well established and, if successful, will effectively augment present chemical controls or actually replace them.

Fungal components of tree mycorrhizae produce antibiotic substances. Mycorrhizae on roots of trees are beneficial in several ways. They increase nutrient-absorbing capacity, provide a physical barrier to attack by soil pathogens, and according to recent results, produce antibiotic substances that protect roots from infection. In the Southeast, one mycorrhizal fungus produces a new compound, diatretyne nitrile, which at 50 to 70 parts per billion concentration inhibits a virulent root pathogen, Phytophthora cinnamomi, the cause of the littleleaf disease of shortleaf pine. Another fungus produces a different antibiotic, which in preliminary tests was found to be more potent against human pathogenic bacteria (Staphylococcus and Streptococcus) than were commercially available antibiotics. The potential usefulness in plant, animal, and human pathology of these and other antibiotics produced by mycorrhizal fungi is under study.

New housing system. From 2 by 4's, boards, plywood, and other common building materials, a house construction technique with new and radically different component parts has been developed for modern homes. House builders in both rural and urban areas will be especially interested in a roof system utilizing a new type of truss and plastic-covered plywood-lumber roof sheathing, walls with wide-spaced double 2 by 4's, and thermal sound insulation, interior finish of gypsum reinforced with low-grade boards, and combination sheathing and exterior siding that will help lower costs and at the same time improve house quality. Because only materials of conventional type are used, the system should find ready acceptance among builders, code authorities, and building inspection officials. This concept also will provide an outlet for relatively low-cost and plentiful grades of lumber and yet provide for the construction of high-quality homes using the latest advances in technology.

Multiproduct potential in standing timber. Increased emphasis upon new products, better conversion practices, and broader product diversification have focused attention on problems of estimating the product potential of timber stands. Conventional inventory techniques, using specific log or tree grading systems, are inadequate for evaluating the suitability of standing timber for a wide range of products. A method was developed that incorporates stand and tree quality measurements necessary to predict potential yield for a number of primary products. Although it was developed in cutover ponderosa pine stands, the principle would appear to offer a high degree of flexibility and versatility in evaluating quality of all timber stands capable of yielding an array of products.

Cutting characteristics of chain saw teeth. Design, construction, and tests have been completed of special instrumentation and a machine for measuring the forces in three planes and energy consumed by a chain saw tooth while cutting through green timber. This is a new advance in technology and the accomplishment opens the way to improved design of chain saw teeth and other cutting devices. Potential annual savings to the logging industry through a 10 percent improvement (expected) in

chain saw parts replacement and cost of maintenance is estimated at $1,850,000 annually. Industry interest in the research is keen.

New comprehensive appraisal of the timber situation completed for the Pacific Northwest. The forest lands of Washington, Oregon, Idaho, and western Montana contain 1,123 billion board feet of sawtimber--about 44 percent of the U. S. supply. The timber industries produce about 51 percent of the Nation's lumber, 87 percent of the softwood plywood, and 25 percent of the wood pulp. Projections of prospective timber supplies indicate that timber consumption will increase 22 percent by 1985. However, in spite of greater log production, total timber-based employment is expected to decline because of continuing improvements in productivity. The prospective decline in employment is especially marked in the sawmill industry. Some increases are anticipated in the other timber-based industries.

Economic guides for managing red pine stands. Data for red pine in the Lake States demonstrate that under most conditions investment returns are highest if red pine stands are thinned regularly to 90 square feet of basal area per acre. Data also were developed to show how financial rotations are affected by stand conditions, investment alternatives, costs, and prices. Application of these findings on the several million acres of red pine in the East would add substantially to long-run sawtimber supplies. Possible increases in timber output from improved thinning practices would also reduce costs of growing red pine by $1 to $2 per thousand board feet.

Related studies describe how to estimate present values of incomes and costs in growing red pine trees for sale as pulpwood or sawtimber. They also illustrate how to (1) compare investment opportunities in growing red pine; (2) determine the amount one can afford to invest to buy land, establish and maintain a stand, or pay in annual taxes or other expenses; and (3) estimate the cost of producing stumpage under specified conditions.

Log exports and the Pacific Northwest economy. A study of logs exported to Japan showed that the average value of logs loaded aboard ship and ready for export was $99.70. The average value of the products that could have been obtained through domestic processing of the same logs was estimated at $95.24. Domestic processing of these logs into kiln-dried lumber would have generated approximately 9 man-hours of employment per thousand board feet. This compares with about 3 man-hours of domestic employment in log exporting. More than 90 percent of recent log exports consisted of No. 2 and 3 saw logs, and less than 4 percent were peeler and select grade logs. Over 80 percent of the logs exported were under 22 inches in diameter, and more than 75 percent were low-value hemlock and white fir.

U. S. hardwood imports grow. During the past 15 years, imports of hardwood plywood have increased 40-fold to 60 percent of total U. S. consumption. Imports of hardwood lumber from tropical countries and Canada also have increased to about 5 percent of the U. S. market. Analysis of domestic markets and timber supplies indicates that the major reason for increasing imports has been a growing shortage of high-quality hardwoods. A rapid expansion in production of fine hardwoods in tropical areas of the world has been another contributing factor. These trends appear likely to continue, and increases in imports of hardwood plywood and lumber are to be expected in coming decades.

The following are examples of progress on related research at State institutions:

The North Central regional project NC-51. Forest Tree Improvement Through Selection and Breeding is setting a high standard for cooperative provenance testing and subsequent breeding of forest trees. Project leaders from nine North Central States are cooperating under vigorous leadership to pool their testing of very complete seed source collections of 18 species, both native and exotic. One Station secures the collection and provides stock or seed to all of the cooperating States. Record keeping is standardized and results pooled, with improvements in planting design and performance analysis being devised as the project develops. Some of the results are now being incorporated in commercial nursery seed procurement practice and breeding is being started, using the most favorable seed sources. Important saw fly resistance has been found in a Scotch pine variety, and interstate testing of a promising pine hybrid is being started this summer.

What are the most profitable practices to apply in woodland management? Among several studies at State Stations aimed at this general problem, recent work at the Indiana (Purdue) Agricultural Experiment Station on Development of Operational Control Techniques for Forest Management, project 1194, has been especially productive. One of the results of research is described as "Dynamic Programming for Management Planning." It involves the first known use of a computer method known as the dynamic-programming-Marhov-chain technique for selecting an optimum plan of management for a woodland area. This has been demonstrated for a 25-acre experimental woodland of central hardwoods, based upon 6 years of records from continuous forest inventory plots.

Another computer program has been written to calculate the rate of return earned by many different regeneration methods for three southern pines. The computer ranked the top 25 methods in order of decreasing rate earned. The program selects the rotation and thinning regime that maximizes rate of return, and permits consideration of pulpwood stumpage price, sawlog stumpage price, location with regard to pulpwood market, land value, annual land management costs, income taxes, and variations in site quality.

I. TIMBER MANAGEMENT RESEARCH

A. SILVICULTURE

Problem

The broad field of silviculture includes the problems of growing and tending forest trees and stands from seed to sawtimber. It deals with reproducing forests both naturally and artificially, with intensive cultural measures for increasing the yield and improving the forest stands, with methods for evaluating and improving the productive capacity of forest soils, and with stand treatments required to perpetuate valuable species adapted to the site. Related to all of these problems are the basic physiological processes involved in tree growth.

Evaluation of soils and sites for the establishment, growth, and development of various tree species is basic to forest management. Knowledge of proper species or mixtures best adapted to particular sites is needed to guide regeneration programs, timber stand improvement operations, and stand conversion. Growth rates in response to cultural measures are the basis for investment decisions. The integration of fundamental and developmental research into systems for managing forest properties is the final phase of silvicultural research. Forest managers need to know how various prescriptions for better forest practices fit together into a unified management program. They also need to know how best to modify the silvicultural practices to accommodate other forest uses such as watershed, range, and wildlife management and recreation on areas managed for timber production.

USDA and Cooperative Programs

A continuing program of silvicultural research is conducted at all nine Forest Experiment Stations and the Institute of Tropical Forestry in cooperation with various schools, State forestry groups, private industries, and other private forest landowners. Included is a comprehensive program of basic and applied research in seed production and seed handling, forest nursery practice, site preparation, direct seeding, and planting techniques for important timber species. Also included at specialized laboratories are studies on the uptake of systemic chemicals, the physiology of wood formation, the control of growth and dormancy, role of mycorrhizae, mineral nutrition of trees, breakdown of litter into humus, physiological control of flowering and fruiting, and growth in relation to soil characteristics. Studies of natural regeneration and of the care and improvement of existing forests through pruning, thinning, weeding, and other stand improvement measures are carried on in all Experiment Stations.

A long-term program of research comparing different silvicultural systems in different forest types and stand conditions is conducted at many of the Stations to provide operational answers for forest managers. Such studies often are conducted in cooperation with timber companies who may provide forest lands or purchase timber under contracts requiring species treatments and records.

Research is being conducted under Forest Service grants at the University of Georgia on uptake and translocation of pesticides by woody plants; at the University of Florida on the biosynthesis of cellulose in trees; at the University of California on the palatability of tree species; and at Washington State University for the development of an ecological classification system in Northern Rocky Mountains. A pioneering research unit at Rhinelander, Wisconsin, is studying the physiology of wood formation of trees and another pioneering unit at Research Triangle, North Carolina, is conducting research on the role of litter in forest soils. The total Federal effort in silvicultural research in the United States amounts to about 145 man-years annually.

A program of research is also carried on under Public Law 480 in Finland, Greece, Israel, Italy, Poland, Spain, India, and Brazil.

Progress -- USDA and Cooperative Programs

1. Site evaluation and soil improvement

The correct choice of species for any given site is essential to maximize profits from timber growing. The soundest basis for this choice is direct comparison of the growth of candidate species. A comparison planting of four native and five nonnative species showed that other pines besides native shortleaf appear suitable for reforesting abandoned fields in the Ozarks. Nonnative loblolly and Virginia pines perform as well as shortleaf pine on loamy sand, silty clay loam, and cherty silt loam, soils which are common to the Ozarks. Planted yellow-poplar, a nonnative hardwood, rivals pines on cherty silt loam ridge tops. Fifteen years after planting, the pines and hardwoods alike exceed 50 percent survival, 30 feet in height, and 4-1/2 inches in diameter. Also important to residents of the Ozarks is the knowledge that eastern white pine, pitch pine, black locust, black walnut, and eastern redcedar are poor planting risks on the sites compared.

In southeastern Ohio, the site index of black oak can now be estimated by means of regression equations which show that black oak grows best on north and east lower slopes and coves, and on soils with deep topsoil layers. South and west upper slopes and ridge tops and stony, fine-textured soil are poor sites for black oak.

These soil-site relations permit comparative evaluation of site quality when trees are absent or the species in question not represented in the stand. Comparative site evaluations were developed for loblolly, shortleaf, and Virginia pines in the Virginia Piedmont. Both loblolly and shortleaf pine site indices were adversely affected by high clay content of the subsoil, but the site index of loblolly pine improved with increasing subsoil depth and on more poorly drained soils, while

that of shortleaf pine did not. Virginia pine site index is affected mainly by texture of the surface soil, decreasing as the clay content becomes greater. Loblolly pine site index is higher than that of shortleaf pine on all soils but especially on wetter soils, which are adverse for the growth of shortleaf. Virginia pine is least sensitive to soil properties and outgrows shortleaf pine on dry, upland soil as well as on poorly drained soils.

Some types of irrigation may be too expensive to show a profit from increased tree growth, but if additional benefits can be realized it may be justified. Depending on natural stream flow to dilute effluents and reduce their toxicity, the paper industry disposes of more than a billion gallons of effluent each day in nearby streams. If present in sufficient concentrations, the dissolved and suspended materials, which add a dark color and strong odor to the water, will kill fish and other aquatic life. New ways to dispose of this waste must be found, and using it to irrigate pine stands is one of the most promising alternatives. In Louisiana, damage to slash pine seedlings irrigated with kraft paper mill effluents depended on the concentration of impurities and the precautions taken to prevent toxic accumulations of residues in the soil. For 3 years, survival was unaffected by the treatments used. During the fourth year, a strong waste called black water caused some mortality, but weaker effluents did not. Long-range effects are being determined by supplementing normal rainfall with annual applications of 20 and 40 inches of effluents during the growing season. Further research is needed, however, before general recommendations can be made, and many aspects of irrigation must be worked out by individual mills. Successful use of the effluent for irrigation will reduce pollution of the streams and rivers and may prove beneficial to pine stands by increasing growth.

Availability of mineral nutrients is also important in growth, perhaps to a greater degree in hardwoods than in conifers. Soils common in the Central States proved to be deficient in nitrogen and phosphorus for growth of potted red oak seedlings. Potassium was not limiting but liming slowed growth, apparently because phosphorus uptake was reduced by fixation in the soil or by suppressed mycorrhizae formation. Fertilization increased growth more in green ash and cottonwood than in red oak and black walnut.

In the Northeast, pot studies and field observations have clearly shown that yellow birch roots develop much more prolifically in humus than in sandy mineral soil. Other studies have indicated that physical factors do not seem to be limiting. Thus the task remained of pinpointing the nutrient deficiencies responsible for root inhibition. A pot study comparing the effects of nitrogen, phosphorus, and potassium combinations with and without lime showed that the presence of phosphorus was essential for any appreciable response in root and stem development. The phosphorus-potassium combination produced the greatest root and stem weights, and gains were consistently better under liming. Results suggest very

strongly that subsoil fertilization with phosphorus and lime should produce marked responses in root and stem development of yellow birch, once the proper methods and rates of application have been worked out.

One of the essentials to develop methods of intensive silviculture is information on soil and foliar sampling and testing procedures. Most methods now in use have been developed for agronomic crops, and an evaluation of these operations and their adaptation to forestry was made in a study of loblolly pine in North Carolina. It was found that soil tests which measured the easily soluble nitrogen, phosphorus, and potassium were good measures of the availability of these elements to trees. Foliage sampled in January or February seemed to provide a better evaluation of the tree's nutrient status than did needles selected at other times of the year. Standard testing and sampling techniques will make it possible to relate tree growth to foliar and soil nutrients, and to devise remedial measures to correct deficiency conditions.

When trees grow, they withdraw nutrients from the soil and deposit them in their tissues. Soil scientists in the Southeast determined nitrogen, phosphorus, potassium, calcium, and magnesium content of loblolly pine trees from 8 to 46 feet in height. There was a maximum rate of annual accumulation of nitrogen in the trees in the size range from 10 to 20 feet. Harvesting a forest crop carries away nutrients, a process which may ultimately affect tree growth. Nutrient removal by harvest of a 46-foot tree was investigated. From these data, it was estimated that one cord of pulpwood (5,000 pounds) including bark removes 0.25 pounds of phosphorus, 1.52 pounds of potassium, 1.69 pounds of calcium, 0.56 pounds of magnesium, and 1.44 pounds of nitrogen. If nutrient removal continues for several rotations, soils of low inherent fertility may become deficient in certain essential elements. Further information on nutrient cycling is required to better understand factors which affect site productivity.

On several million acres of forested peatlands in northeastern Minnesota, black spruce is the most abundant tree. Variations in growth rate are extreme, however, and extensive areas are incapable of producing trees of commercial size. A recent study shows that these variations in growth rates are related to distinct "topographic" features of the bogs. Channels of active water movement termed "water tracks" in black spruce bogs are associated with rich floras and high productivity, while adjacent "muskegs" exhibit less varied floras and low production. Water tracks carry nutrients into the bog from mineral soil sources upslope, while "muskegs" are dependent upon recycling of nutrients and upon those carried by precipitation. Foliar analyses demonstrated that nitrogen and phosphorus levels were high in black spruce from such a "water track," but deficient in a nearby "muskeg" isolated from mineral-bearing waters.

2. Artificial regeneration

a. Seed production and handling

The southern pine region has 88 seed orchards totalling 2,716 acres and 152 seed production areas totalling 5,449 acres. Thus, over 8,100 acres are being managed intensively for seed production. Accurate methods for predicting seed yields and estimating cone and seed quality are essential for planning seed requirements, meeting seed certification standards, and planning cone collections. In a slash pine seed production area, owned by the Continental Can Company in Georgia, it was found that there were 10,368 seeds per pound from certain trees while others had 25,699, or 2-1/2 times as many. Also, the study showed high correlation between binocular counts of the cones on trees in July and the number of cones collected in September. Thus, seed yields can be predicted a few months in advance of the usual collection date in the fall. Because of the extremely wide range in number of cones on individual trees, choice of trees greatly affects seed collection costs. Collection costs were $7.02 per pound for all 100 trees in the study. Collecting only from trees with more than 100 cones would have yielded nearly as much seed, 91 percent, but would have reduced costs by 47 percent to $4.09 per pound. Collecting from 200-cone trees only would have yielded 61 percent of the total seed crop but would have cost only $2.65 per pound of seed. Thus, it would be profitable for the collector to estimate the cone crops and his seed requirements in advance and limit cone collection to only enough high-yielding trees to supply his needs.

Extraction and processing of sand pine seeds have taken on new importance as this species gains recognition in the sandhills of southeastern United States. The fruit of sand pine behaves differently from that of most other southern pines. Specific gravity cannot be used to predict ripeness of cones and seed but cone color is a good ripeness index. Storage tests indicate that at a moisture content of 6-15 percent and temperatures of 0-34°F., sand pine seed can be stored for at least 2 years with no loss of viability; however, 10 percent moisture content and 25°F. is recommended as the most prudent storage condition.

Information on the ripening, collecting, and storing of Virginia pine cones and seed is needed as use of this species increases in both seeding and planting. Scientists in Maryland found that seeds collected 2-1/2 months before natural seedfall ripened under prolonged cold dry storage in closed containers, with or without prior storage of the cones at room temperature. Such treatments are easy and can greatly relieve time pressures in seed collection. Without such treatments cones should be collected only when mature: that is, when color changes from green to purple and specific gravity drops below 1.0. In this study the treatments recommended usually gave germination values of 60 to 90

percent, compared, for example, to 2 to 7 percent for seeds collected on August 30 and subjected to unsuitable storage treatments.

The buoyancy of longleaf seed exceeds that of most other pines, and the literature contains no report of a liquid with a suitable specific gravity for separating full and empty seed. In recent research at Alexandria, Louisiana, n-pentane gave excellent flotation separation on several lots of dewinged longleaf seed that had been stored at moisture contents of less than 10 percent. The specific gravity of this compound is 0.62 at room temperature and it boils at 97°F. Sound longleaf seeds will sink and the empties will float. Although 2 or 3 minutes is considered ample time for fractionating small lots of seed, germination tests showed that viability of the seed was unharmed when they were soaked for 4 hours in pentane. This method of separating full and empty seed is most useful for small lots, such as those obtained in controlled pollination. It may also be used with large lots, provided proper precautions are taken when handling the pentane which is highly flammable, and vaporizes at room temperature.

Seeds of many tree species need stratification--that is, storage under cool, moist conditions that simulate over-wintering on the forest floor--to prepare them for seeding in the field or nursery in the spring. Many occasions arise, however, when time is too limited for stratification, which requires weeks or even months. Soaking seed in hydrogen peroxide has proven to be a speedy and satisfactory substitute for stratification for laboratory use. Now, germination in the field of unstratified Douglas-fir seed has also been speeded by presowing treatment with dilute hydrogen peroxide. However, germination was not naturally hastened in ponderosa and sugar pine seed; ponderosa pine germination may even have been delayed. Hydrogen peroxide treatment of the seed had a generally beneficial effect on early seedling survival of all three species apart from its effect on germination. Study results have provided us with a reliable and fast working alternate to stratification for preparing Douglas-fir seed for spring sowing in nursery or field.

b. Nursery practices

Chlorosis developed in a southern nursery in May and spread rapidly to all parts of the beds. By late June, more than 10 acres of seedlings were seriously diseased, and unless a control could be found, complete loss seemed inevitable in spots as large as one acre. A lime-fertilizer trial demonstrated how pine seedling chlorosis could be minimized by adjusting soil pH to between 5.5 and 6.0 and moderately fertilizing to maintain growth. Exact rates of fertilization were not established because seedlings were using nutrients remaining from earlier applications. The study showed that improper use of lime and fertilizer creates imbalances between iron and manganese in the seedlings, inducing chlorosis.

The temperature regime of the nursery can influence the vigor of ponderosa pine seedling root systems. In California, ponderosa pine transplants from a nursery with warm night temperatures produced more and longer roots than transplants from another nursery with cold night temperatures, although the day temperatures of the two nurseries were similar. A night temperature greater than 5°C. and averaging no more than 10° to 14°C. cooler than day temperatures seemed to yield the greatest root production. This day-night temperature difference may prove to be a valuable criterion in selecting nursery sites for ponderosa pine.

In Puerto Rico with its yearlong growing season, seedlings planted with bare roots survive poorly, so planting stock is grown in plastic bags that can be planted directly in the field. The medium for growing potted pine seedlings must be plentiful and cheap, as well as biologically successful. As in previous trials, seedling development was best in fresh sphagnum moss, but was also satisfactory in rotted sawdust and vermiculite, pure or mixed together. Shredded coconut fiber, recently introduced, was no better than sawdust and much more expensive. Sphagnum moss is excellent where readily available and cheap, but well-rotted sawdust, alone or in mixture, is more economical in Puerto Rico and quite satisfactory.

c. Seeding and planting

The success in direct seeding of southern pines since the late 1950's has stimulated renewed interest and numerous trials in other sections of the country. To focus attention on direct seeding, review the state of the art, and point the way toward future progress, the Northeastern Forest Experiment Station, the Maine Forest Service, and the Universities of Maine and Massachusetts sponsored a symposium on direct seeding in August 1964. Papers presented by Forest Service scientists dealt with critical problems of several important species. Black cherry seed that is after-ripened at room temperature and then stratified germinates well but satisfactory height growth requires protection from deer and control of competing vegetation. Sugar maple may need shade for satisfactory survival and early height growth. White pine also seems to become established best under an overstory that retards surface evaporation and provides some shade; the white pine studies also suggested that the widely-used arasan-endrin seed coating did not repel rodents as effectively as in the South, but observed losses could have been caused by other seed predators.

Seeds of Atlantic white-cedar can be collected in moss or litter from the forest floor, stratified, and sown without repellent treatment, but successful stand establishment is often precluded by deer browsing. Untreated seeds of pitch and shortleaf pines can be sown on upland sites if they are given a light covering of soil, such as provided by a brush-hog. Red and jack pine seeding in the Pocono Mountains in New Jersey requires reduction of existing vegetation, use

of seed repellent, and covering with soil; because the seedbed is humus over rocks, lethal soil moisture stress occurs in about one year in three. In the Lake States, direct seeding of jack pine is a proven practice, but slow germination and height growth are serious handicaps in seeding of red pine and white and black spruce, which indicates need for more intensive site preparation.

In southeastern Alaska, aerial seeding of Sitka spruce and western hemlock resulted in only 850 seedlings per acre, a seed-seedling ratio of only 57:1. Four-milacre stocking was 28 percent on a south-facing slope, 48 percent on a north-facing slope, and 33 percent on the valley bottom. Natural seeding in the same year increased stocking on all aspects to above the 40 percent, or 100 well-distrbuted seedlings per acre, considered adequate for extensive management.

In the South, direct seeding has been extremely successful on large holdings. The method also seems well suited to small tracts but few have been seeded. Trials made on small privately-owned tracts from 1962 to 1964 showed that broadcast sowing is as effective as planting while spot sowing is slightly less effective. With aid from State and Federal agencies for site selection, species choice, and site preparation, seeding is inexpensive and fast, and requires no more skill than for planting nursery-grown seedlings. Costs of seeding are above half those of planting.

The increasing scarcity and high value of black walnut has stimulated a heavy demand for information on its planting and culture. Studies in the Central States show that 1-0 seedlings with the largest stem diameters had the highest survival, and were twice as tall and growing twice as fast at 5 years of age as seedlings with smaller stems. In addition, successful establishment of black walnut plantations requires choice of proper site, correct planting techniques, and clean cultivation. Soils should be deep and fertile with good external and internal drainage for best growth. With care to avoid twisting and doubling the roots, good survival and early growth will be assured. For rapid growth during the first few years after planting, it is necessary to keep down weed competition through cultivation or by the use of chemical herbicides. Plantings in forest openings must be carefully tended also by keeping the volunteer trees and shrubs from killing out the walnut.

In Puerto Rico, potted seedlings are used in establishing forest plantations to insure satisfactory survival, but it is much more expensive and physically more difficult than the use of bare-rooted seedlings. With care and on moist sites, initial survival and growth of bare-rooted seedlings was as good as potted seedlings. Growth of cadam greatly exceeded that of Honduras pine on the heavy clay soils. Further studies will be necessary to obtain equally satisfactory results by the operational planting crew, and on less favorable sites.

The ability to stimulate and maintain seed production at a high level would simplify and facilitate orderly silviculture. In a PL 480 project in Finland, distribution of Norway spruce pollen was related to the number of degree-days above 5° C. accumulated since the preceding winter. A peak pollen discharge occurred after degree-days reached 135-145. The amount of pollen and the number of female flowers were positively related to the dominant stand height. The movement of pollen grains into the pollen chamber of female flowers was inhibited by spring frosts, which occur frequently during the flowering period. The proportion of seed that was sound was related to the amount of pollen cast and to failures of ovum fertilization. This study pinpoints some of the reasons for poor seed crops and provides a promising technique for judging the time of pollen maturity, very useful information to tree breeders as well as foresters.

3. Natural regeneration

Successful natural regeneration of any species requires adequate seed, favorable seedbed conditions, and control of plant competition. Consequently, it is appropriate to assess progress in research on natural regeneration in terms of these requirements.

In Sierra Nevada mixed conifers, a good seedfall of nearly 200,000 seeds per acre resulted in over 8,000 seedlings the following spring, of which 5,500 remained 12 years later. In contrast, the next seedfall of only 7,000 seeds per acre produced only 109 seedlings the following spring. Logging created a variety of seedbed conditions of which light litter was nearly as favorable as bare soil for all species. Sugar pine and ponderosa pine survived best in full sunlight, incense-cedar performed well in half shade, and white fir survived best in full shade. The pines outgrew the associated species more than two to one.

More detailed investigation of factors affecting natural establishment of Sierra Nevada mixed conifers showed that sugar pine and white fir were favored by a light overstory which prevented frosts. However, the overstory severely retarded growth of the seedlings. Incense-cedars would have been more numerous if cutworms had not selectively taken this species. Although complete clearing created conditions leading to high surface-soil temperatures, particularly on south-facing slopes, stem insolation did not appear critical in survival.

These observations indicate that the species composition of a new stand can be controlled to a considerable degree by varying the method of cutting the parent stand. Thus, different management objectives--aesthetic, wildlife, and ecological objectives as well as timber production--probably can be met with the knowledge obtained from comprehensive silvicultural studies.

A major obstacle to natural regeneration of Engelmann spruce-subalpine fir in northern Idaho is the susceptibility of seed sources to windthrow. Seed-tree groups, narrow strips, and small blocks are highly vulnerable to windthrow, which means not only reduced seed supplies but also loss of the volume in the windthrown trees. Five years after cutting in 1929, only 38 percent of seed-tree groups retained one or more live trees. One-chain-wide strips suffered similar losses. By 1954, very few of the seed-tree groups or strips could be identified. In contrast, mortality in a partially cut stand was not unduly high, perhaps because the stand was below the crest of a ridge and reasonably protected from high winds. Evaluation of this early reproduction cutting indicated that side seeding would be effective up to 660 feet. Therefore, clearcut blocks or strips are recommended for moist and windy sites; partial cuttings may be used on well-drained soils or protected sites.

In central Idaho, where regeneration of ponderosa pine frequently fails because of deficient soil moisture, germination and seedling survival were observed for 3 years on scarified and comparable unscarified sites representing a variety of aspects and slopes. Three years after scarification, stocking (tree distribution) on milacre quadrats averaged 40 percent on the scarified areas and 3 percent on the unscarified areas. Scarification resulted in adequate stocking on the northeast aspects but results were inconsistent on southwest aspects. The ratio of disseminated seed to established seedlings (after 3 years) ranged from 27:1 on northeast aspects to 55:1 on southwest aspects, and 290:1 on ridges. In 1963, after a much smaller seed crop, another survey of six of these plots, including three unscarified, showed that all had over 3,500 seedlings per acre and five were more heavily stocked than in 1959. June rainfall was 4.15 inches compared to 0.66 inches in 1959 and July temperatures averaged 5° F. below normal. These observations show that aspect, slope position, rainfall, and temperature as well as scarification are important factors in ponderosa pine regeneration.

In contrast to many other species, natural regeneration of redwood apparently is dependable. This conclusion is based on studies conducted on the Redwood Experimental Forest in California. Redwood stumps began to sprout within a few months after the trees had been cut. Abundant seed was dispersed on freshly disturbed soil the first year following cuttings. During 5 consecutive years seed production continued to be abundant. Many seedlings became established on mineral soil and burned seedbeds. Five years after cutting, sprout heights up to 15 feet and seedling heights up to 4 feet assured that a new forest is well started. Both seeding and planting are expensive ways of reforestation--from $30 to $100 per acre. Where natural regeneration is prompt and results in satisfactory stocking, the dollar savings are substantial. When, in addition, the species grows as rapidly as redwood, the prospects of good profits are greatly improved.

Knowledge of paper birch seed production is needed to aid in planning for natural reproduction of this species. Medium or better seed crops were estimated to occur about 50 percent of the time in both the Northeast and the Lake States. In northern New England, up to 96 percent of the total seed crop was dispersed by the end of October. Highest recognition (77 percent) coincided with years of highest seed production. Seed weight was greatest in good seed years and the heavier seed had the better germination.

Although environmental studies have provided fairly abundant information on the requirements of paper and yellow birch for germination and growth, further evaluation was needed of the importance of various environmental factors under actual field conditions. A survey of 3-year-old patch cuttings on the Bartlett Experimental Forest in New Hampshire revealed that small patches of one-tenth to one-third acre can result in successful birch regeneration. Although seedlings were most numerous on exposed mineral soil, height development was best where the humus remained. Competition, especially from pin cherry and raspberry, limited the number of free-to-grow birch, particularly in the second-growth (as compared to old-growth) stand.

Little is known about regenerating two important red oaks--cherrybark and shumard oaks--which are capable of producing high-quality sawlogs within 60 years. Results from a selection cutting in a mixed bottomland hardwood stand on the Santee Experimental Forest showed that red oak seedlings became established in abundance in a good seed year, but did not develop satisfactorily. Seven years after a selection cut only 3 percent of the red oak seedlings in the openings were more than 12 inches tall. Number of seedlings was directly correlated with diameter and size of opening and negatively correlated with distance from seed trees. Fewer seedlings were associated with the very large trees. The larger openings had more seedlings at any given distance from edge of opening. Probably the most significant factor revealed by this investigation was that for openings up to 200 feet in diameter (or nearly an acre in size) established seedlings were not developing into sapling sizes in adequate numbers. In order to manage these species under the selection system, large patches (actually a form of even-aged management) are apparently necessary. Or, expressed in another way, even-aged management appears to be the system that should be used for these species.

Among the numerous obstacles to natural regeneration and controlled breeding of white oak is premature abscission of acorns. In eastern Kentucky, over 90 percent of white oak acorns dropped prematurely in 2 successive years. More than 80 percent of the drop occurred during early stages of development in spring. Causes of this premature drop must be found before prevention techniques can be developed.

Eastern cottonwood (Populus deltoides) is one of the most important hardwood species found in the Mississippi Delta. Cottonwood stands along the lower Mississippi River are often followed by undesirable species. Although abundant seed falls to the ground nearly every year, the only way to regenerate cottonwood in openings of older stands has been through plantings which require cultivation. Investigation in Mississippi showed that ditches about 8 inches deep and 6 feet wide provide the bare, moist mineral soil needed to establish the cottonwood and provide the necessary weed control for survival and growth. The ditches may be dug from January through May by either a bulldozer or a giant plow. Cutting or deadening the overstory is necessary, so that the young cottonwoods will have nearly full sunlight by July of the first year. The minimum number of seed trees required is one tree per two acres, although one or two trees per acre would probably be better. This treatment has been most successful on silt or sandy loam soils. Ditching was done at approximately one-third to one-half the cost of planting. Cost of establishing would average from $5 to $25 per acre, depending on stand conditions and type of equipment used.

4. Multiple-use silvicuture

As more forest lands are dedicated to multiple use, they will increasingly require a modification of silvicultural practices designed to meet the selected management objective, whether this objective is a single use or product, or a combination of two or more. Silvicultural prescriptions for a few of the simpler combinations can be prepared from currently available knowledge, but a great deal of additional research will be needed to design silvicultural systems to maximize the return from the multiple and complex combinations.

The onrush of problems in environmental pollution, weather modification, and over-use of resources by man and animals has spotlighted the important role of baseline ecological studies of the undisturbed forest environment. One of the research natural areas set aside over the past 3 decades for this type of research has been under study by the Forest Service for 20 years to detect ecological changes. The research showed that this virgin beech-birch-maple-hemlock stand of several thousand acres in Tionesta Research Natural Area in Pennsylvania has actually been greatly modified through over-use by deer under light hunting pressure. Witch hobble, a prime deer browse species and once the leading shrub in this forest, has been virtually eliminated, and nearly all the hemlock and hardwood seedlings in certain portions of the tract are dead. The understory as a whole decreased in cover density and in number of stems on 62 percent of the area. The decimation of hemlock reproduction and witch hobble resulted in a shift in browsing to the available but less palatable beech seedlings and root suckers which have been increasing in number and size. The climax forest type is not perpetuating itself under present conditions. Unless the animal pressure on this virgin forest is relieved, it will endanger the scientific usefulness of the area for baseline ecological research.

Preservation of the natural landscape may present some of the most difficult problems of forest land management. In the Washington Cascade Range, many of the flower-rich subalpine meadows, so attractive to recreationists, have been invaded by subalpine fir. These are large-scale invasions involving large portions of meadow areas. Ninety percent of the invading trees in one area studied were between 30 and 48 years old; none were younger than 18 years. The likely explanation for the invasion is a temporary amelioration of climatic conditions in the first half of this century. If these meadows are to be retained, mechanical removal of the invading trees will be necessary.

Most combinations probably can be compatible, however, and quite possibly more profitable than any one use alone. A review of timber management trends in the slash-longleaf belt reveals that timber management programs can be--and in many cases are--compatible with forage and wildlife uses. Site preparation measures tend to promote a greater variety of food plants for wildlife, and provide better nesting areas for quail and turkey in particular. The wide spacings which are conducive to maximizing sawtimber and gum yields offer good opportunity for several years of forage production.

Acorns are not only needed to assure oak regeneration, they are also an important wildlife food. Pin oak is a common timber tree in the Central States on wet, heavy soils often flooded to attract ducks. During 9 years of observation in southeastern Missouri, crops ranged from less than 1,000 to more than 200,000 acorns per acre. Annual variability was not affected by stand characteristics or flooding, but insect infestation was relatively less in larger than in smaller crops. Thinning reduced acorn production only temporarily--after 2 years the lighter stands produced more acorns than the denser stands. Low levels of stocking, down to 40 square feet of basal area, result in rapid growth of the trees for timber and larger acorn crops for wildlife food and regeneration.

If multiple-use management of two or more resources is to be successful, we must first know how to manage each resource alone. Many gaps remain in our knowledge of silviculture for timber production. Research in silvicultural systems, characteristically long-term, continued during the past year and additional useful knowledge was accumulated.

Forest land that fails to restock quickly and adequately following harvest of mature timber represents lost revenue to landowners. Eleven percent of the coastal western hemlock type is classed as nonstocked. Intermediate results from a shelterwood harvest study indicate that abundant reproduction can be secured under a broad range of shelterwood densities. Little, if any, growth need be sacrificed in the resideual overstory, compared to an uncut stand. If regeneration is already present when the mature stand is harvested, rotation length is minimized and a continuous forest aspect is maintained in these scenic coastal forests.

Timber owners must know the costs of logging in order to reach sound management decisions. At the Challenge Experimental Forest in California, areas have been logged by the group selection method, which removes small clumps of trees to create openings only 30 to 90 feet in diameter in the forest. This method of cutting favors establishment and growth of Douglas-fir and sugar pine, which are more valuable trees than ponderosa pine. Total costs for logging by the group selection method varied from $7.04 to $7.99 per thousand board feet, which compares favorably with other methods of cutting already tried. This means that the forester now has another harvesting technique available which costs no more for logging, but which may improve the composition of the forest.

The selection system may have many applications in multiple-use management, but information is needed on its long-range effect on species composition to determine its suitability in different situations. A comparison of different silvicultural systems in cove hardwoods in West Virginia showed that with the single-tree selection system: (1) the proportion of sugar maple will increase appreciably and consistently, and (2) the proportion of the valuable yellow-poplar, red oak, and black cherry will decrease to a point where these species are no more than minor components of the stands. Thus, species composition can be controlled by varying the size of opening made in harvest cuts. These results indicate the degree of flexibility possible in silvicultural systems to meet multiple-use objectives.

Clearcutting of openings in hardwood forests is one method of obtaining desirable reproduction, but it may result in the formation on border trees of epicormic branches, which degrade the lumber. A study of border trees left around patch cuttings in West Virginia indicated that epicormic branches were more abundant on the upper stems and on the side of the tree facing the opening. Among the three species studied, epicormic branching was greatest on red oak, intermediate on black cherry, and least on yellow-poplar. These results help in designing silvicultural treatments for these high-value hardwood species.

5. Stand improvement

Cost reductions through the use of undiluted herbicides applied in small, precisely measured amounts by metering injectors are now being realized. Research in the South resulted in guides for dosage and spacing of incisions by season, species, and tree size. Operations in late spring and early summer, when trees are easiest to kill, achieve maximum savings. Trees over 9 inches d.b.h. should receive double the amount of herbicide prescribed for trees 4 to 9 inches in diameter. Two- and 3-inch trees require two jabs on opposite sides of the tree. Blackjack oak is easier to kill than red oak; sweetgum is the most difficult. Bitter pecan and other unwanted bottomland species can also be effectively controlled by this method. Savings are about $1.50 to $2.00 per acre resulting from injecting undiluted rather than diluted herbicide. Economies result from lower chemical costs, less labor, less time for refilling tools, and elimination of an oil carrier.

Aerial application of herbicides also promises to be economical but further study is needed to make it consistently effective. In southwestern Oregon more than a quarter million acres of commercial forest land are occupied by nonproductive brushfields that must be eradicated before the land can be put back into forest production. A study in almost impenetrable evergreen brushfields showed that a planned program of burning and aerial spraying with herbicides can clear some sites enough to allow reforestation. Aerial sprays were much more effective on resprouting shrubs than on vigorous mature shrubs. The information provides a basis for developing effective reclamation methods in the brush type of southwestern Oregon. It also permits more logical planning and better economic evaluation of brushfield reclamation projects in other areas.

In the Appalachian region, sites with poor hardwoods are better suited to the growth of conifers, but conversion is costly. Aerial spraying appears to be an economical method of removing the hardwood competition. In West Virginia, aerial spraying of 2, 4, 5-T by helicopter killed more than 90 percent of such species as the oaks, but the hickories and serviceberry were only slightly affected. Position of the trees in the canopy was also an important factor; the overall killing effect was good on the overstory, but kill was low in the understory.

The use of herbicides sometimes has unexpected and undesirable results. In New Jersey, damage to untreated trees occurred through root grafts when 2, 4, 5-T in fuel oil was applied with injectors to sweetgum. This damage affected 20 percent of the dominant trees in one stand, but occurred only among stems 16 inches or closer to treated trees. The damage seemed due to root grafts: of two dead trees examined, both were connected with root grafts to nearby injected stems. To prevent damage in thinning sweetgum stands, injectors should be used only on stems at least 1-1/2 feet from crop trees; nearer stems should be cut or girdled.

Much of the popularity of herbicides in forestry stems from the degree to which their use facilitates the rehabilitation of previously unmanaged stands. Stands that are well managed throughout the rotation seldom develop the amount of undesirable material found in unmanaged stands. Some evidence of this fact was obtained in West Virginia. In a study in Appalachian hardwoods, a single cull-killing operation reduced the volume in defective trees from about 17 percent to less than 1 percent of total stand volume. Cull material in the defective portions of merchantable trees amounted to about 13 percent but it was reduced to about 5 percent by the time of the third cutting in these stands. Under intensive selection management of hardwoods, cull will probably level off at these percentages rather quickly.

6. Animal damage

Earlier research by the Olympia, Washington, animal damage research project showed that at least 11 milligrams of TMTD (tetramethylthiuram disulfied) were needed to protect Douglas-fir seedlings from rabbits. To have this amount retained on the seedlings, recent research shows that the rate of application in the

nursery to 2-0 Douglas-fir seedlings should be about 9.0 gallons of the repellent formulation per 1,000 square feet of seedbed area. This amount will provide seedlings with TMTD coatings of 12 to 19 mg. per seedling and should afford protection in the field throughout the dormant season. This application rate costs only 10 cents more per 1,000 seedlings than that previously recommended and is easily justified to obtain adequate protection. For each acre given protection by the new rate of TMTD application, as much as $30 per acre of second-year replanting costs can be saved.

While TMTD is an effective rabbit repellent if applied correctly, considerable amounts reach the soil in the nursery. Because an adverse effect was possible, TMTD was investigated in two nursery soils. Initially, the chemical decreased soil respiration and impaired nitrification. However, depressing effects were gradually overcome as TMTD degraded in the soils. The degradation rate depended on soil properties and initial concentration of the chemical; the degradation period varied from 2 to 6 months.

In the Cascade Range of the Pacific Northwest, damage to dormant buds of upper-slope seedlings and saplings retards height growth and deforms trees. Detailed observations on true firs and associated species near Mount Hood, Oregon, provided strong evidence that damage was caused by grouse. Results also showed that the grouse preferred buds of true firs over those of Douglas-fir and that hemlock and cedar were left undamaged. If grouse prove to be the damaging agent on other areas as well, control measures may be needed to maintain tree growth, quality, and desired species composition.

In South Jersey swamps, white-cedar is a prized timber species and most areas have been clearcut four or five times since the early 1700's. But deer so relish the twigs and foliage that in some areas they are limiting white-cedar reproduction. Small plots, fenced and unfenced, were established in a wildfire burn of July 1954; they had 111,500 or 210,700 seedlings per acre in September 1955. Nine years later the fenced plot still had 57,000 cedars per acre but the unfenced plots had only 1,440--too few and too poorly distributed to form a well-stocked stand. This species often has 1,600 stems per acre at 45-50 years, and that number of dominants in the fenced plot averaged 10 feet tall in 1964, seven times the height of the fewer dominant stems on quadrats still stocked in the unfenced plot. These results show that on many sites excessive deer browsing is decimating species valuable both for timber and wildlife food.

7. Growth requirements

Studies of tree growth in relation to soils have shown that the soil properties which determine moisture availability are of primary importance to tree growth. Consequently, measures to increase moisture supplies might substantially increase growth. In central Oregon, sapling ponderosa pine stands thinned to 250 and fewer trees per acre and with understory vegetation removed had 10-year growth

of more than 4 inches in diameter at breast height, while stands with 1,000 stems per acre grew only 1.7 inches in 10 years. Where the understory remained, diameter growth was 0.1 inch less under the heaviest stocking and about 0.5 inch less in all lighter stockings. Soil moisture measurements showed that significantly and substantially more water was available in the stands with fewer trees and no understory vegetation.

In southern Missouri, killing all understory and overstory hardwoods increased 10-year growth of 30-year-old pine stands by about 40 percent from 575 to 810 cubic feet per acre in unthinned stands and from 710 to 990 cubic feet per acre in thinned stands. The combination of thinning pine and controlling hardwoods increased pine growth 72 percent over that of unthinned pine stands with hardwoods. These results were observed during a period of comparatively low rainfall. Growth differences due to hardwood control probably will be less in years of normal rainfall. As costs of controlling hardwoods in pine stands decrease, this practice may become economically feasible.

The comparative photosynthetic response of plants to various environmental conditions is a major determinant of the species composition of a plant community. Knowledge of such responses permits better management of plant communities for various purposes. In the Pacific Northwest, photosynthetic rates of Douglas-fir, grand fir, hemlock, Sitka spruce, and noble fir seedlings were highest on overcast or partly cloudy days; Scots pine photosynthesized most on clear days. The superiority of overcast or partly cloudy days was probably due to higher relative humidity on such days because photosynthesis was found to be greatly affected by leaf moisture stress. Low relative humidity increases leaf moisture stress; low soil moisture intensified the effect of low humidity. Below 1,400-foot candles of light, species ranked in photosynthetic rate as follows: grand fir, hemlock, Sitka spruce, Douglas-fir, noble fir, Scots pine. Grand fir, Sitka spruce, and hemlock reached maximum rates of photosynthesis at about 14 percent of full sunlight, Douglas-fir at 16 percent, noble fir at 20 percent, and Scots pine at 26 percent.

The photosynthetic capacity of the foliage of older trees is less than that of seedlings. A study in 38-year-old Douglas-fir showed that, expressed per unit weight of dry foliage, suppressed trees possessed higher photosynthetic efficiency than codominants, which in turn were slightly more efficient than dominants. Diurnal patterns of photosynthesis differed in trees of different crown class. The rates of photosynthesis and nocturnal respiration commonly fluctuated within each diurnal pattern, despite apparently stable environmental conditions. Depressed patterns occurred under hot conditions in summer and under cool foggy conditions in autumn.

If knowledge of photosynthetic responses is to be useful in silviculture, means of modifying the environmental factors that affect photosynthesis must be developed. In studying birch regeneration, the Northeastern Station found that small openings offer a particularly good opportunity to control exposure to light. Calculation and plotting of sunlight patterns showed that the size, shape, and orientation of openings

can be varied to obtain light conditions ranging from full sunlight to no direct sunlight at all (at 44° north latitude); and from exposure only in the middle hours of the day to exposure only in the early morning or late afternoon. The pattern and duration of sunlight and shade affect evaporation and transpiration, soil and air temperature, soil moisture, snow accumulation and melting, frost occurrence, litter decomposition, and many other factors and processes that determine composition and growth rates of vegetation. The silvicultural manipulation of openings is meaningful for wildlife, watershed, and recreation values as well as for timber.

Forest yield estimates can be seriously affected by growth reduction resulting from defoliation. In a study of effects of the 1944-56 spruce budworm outbreak in eastern Oregon, it was found that grand fir, the most vigorous before the outbreak, suffered most reduction in growth; Engelmann spruce was intermediately affected; and Douglas-fir and ponderosa pine were least affected. The drastic reduction in growth of grand fir apparently relieved intermingled Douglas-fir and ponderosa pine of competition so that the latter were not so seriously affected by the insect attacks. Severity of defoliation was the determining factor in growth recovery. The data on growth decline and recovery will help in recalculation of yield estimates.

Knowledge of the effects of environmental factors on the seasonal course and amount of growth is of value to practicing foresters as well as to forest scientists. In a PL 480 project in Finland, the investigator found that diameter growth of pine, spruce, and birch in a swamp forest was positively correlated with minimum daily temperature, was increased over controls where a straw mulch reduced soil temperature and surface evaporation, and was greatest where 20-inch-deep drainage ditches were spaced about 50 feet apart. Air temperature had no effect on initiation of height growth but the period of fastest height growth occurred about 1 month earlier in a greenhouse than outdoors. The period of height growth lasted longer in seasons when more degree-hours over 5° C. occurred, but total height increment was not affected. In contrast to the response of diameter growth to soil temperature, height increment where soil was cooled was less than in control plots. Flowering of pines was closely related to air temperature, flowering occurring every year about the same number of degree-days after the beginning of height growth. Soil temperature did not affect flowering but more flowers occurred on fertilized plots. The possibility of specialized applications of silvicultural measures, such as prescribed burning or maintenance of an understory to control soil temperature fluctuations, can be assessed with fundamental facts such as these.

A PL 480 project in Poland showed that annual height growth of Scots pine is most sensitive to precipitation from the preceding November to July of the present year. An 11-year-old stand grew the most during a 9-month period with 410 mm. of precipitation, a 30-year-old stand with 480 mm., and a 40-year-old stand with 440 mm. Estimated annual consumption of water by pine stands ranged from 160 to 190 mm. Water consumption was greatest during the period of culmination of annual height growth. Diameter and height growth were not affected by depth to the water table--which was sampled to vary from 1.0 to 11.0 meters--alone or in combination with

precipitation. Knowledge of the water requirements of forest stands is fundamental to irrigation or manipulation of water tables to maximize stand productivity.

In Israel, tree growth was studied in terms of terminal growth and cambial activity, which control the responses of trees to environmental factors and cultural treatments. In the three species of evergreens investigated (Acacia raddiana, Eucalyptus camaldulensis, and Pistacia lentiscus) no correlation was found between either the terminal growth or the cambial activity and the four climatic conditions applied (high temperature--long day, high temperature--short day, low temperature--long day, and low temperature--short day). As long as the temperatures applied were not low, the cambial activity was continuous. Under these conditions a sporadic terminal growth occurs from time to time. In deciduous trees (Robinia pseudacacia) the application of low temperature--short day (winter conditions) will induce dormancy in about 6 weeks. At high temperature--short day conditions, Robinia plants exhibit a continuous cambial activity although the buds become inactive. This activity results in a latewood type xylem. However, under the same conditions, occasional growth flushes occur from time to time from dormant axillary buds. The wood produced under high temperature--short day conditions but below a sprouting bud is of the earlywood type. Thus, in Robinia the effects of the environmental factors on the type of cambial activity are at least partially mediated by the buds.

Some silvicultural practices are thought to be detrimental to soil quality in the long run. In another project in Finland, weed control chemicals and soil sterilants used in nurseries retarded the incidence of mycorrhizal infection but did not affect later development of mycorrhizae. Also, slash burning did not seriously retard mycorrhizae formation, even though it sterilizes the soil surface and causes a temporary reduction in soil acidity. These findings offer some assurance that the soil effects of the silvicultural practices investigated are temporary.

Recent pioneering research on the physiology of wood formation has indicated that the size of cells produced in the wood of pines is regulated by auxin, and the cell wall thickness by the supply of photosynthate. This concept was extended in recent research to determine what controls the shape of the tree bole, which in turn has a lot to do with its volume and value. Four-year-old larch trees, pruned to different intensities, were exposed to winds with and without guys to restrain their bending. Studies of the amount and type of wood produced under these conditions supported the concept that pruning induces an upward and wind a downward distribution of growth on tree stems. The size and vigor of the crown determines to a large extent the distribution of growth along the stem, and thereby determines the form of the bole. Under wind stress, growth is preferentially distributed to areas of physical stress, probably through the action of auxin. This "stimulatory" distribution of growth under wind stress was accompanied by a reduction in height growth of the trees compared with the growth of trees guyed to prevent bending. Photosynthate is apparently diverted from height growth to wood formation under the stimulus created by wind sway.

Accumulated silvical information about important forest tree species was published in 1965 under the title, "Silvics of Forest Trees of the United States." This handbook, the result of the collective efforts of Forest Service scientists, consists of silvical descriptions of 127 different forest tree species. Most of those descriptions were published individually, as they were completed.

The descriptions follow a standard outline and each includes an accurate map of the natural range of the species. Basic information on climate, topography and soils, and associated trees and shrubs is followed by a description of the reproductive cycle, requirements for stand regeneration and early growth, growth rate and influencing factors, principal enemies, and recognized races and hybrids.

This handbook is the second comprehensive summary of fundamental information on American forest trees by the Forest Service. The first was the "Woody-Plant Seed Manual," published in 1948 as USDA Miscellaneous Publication 654, and still the standard reference on seeds of forest trees of the United States. The silvics manual should be useful to the practicing forester as well as to the forestry scientist, teacher, and student, because it lists not only the important source publications but also provides a concise summary of critical biological requirements of each species, the basis for sound management.

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B. TIMBER MEASUREMENT AND MANAGEMENT PLANNING

Problem

Intensive management of the commercial forests of the United States requires efficient methods of measurement of the contents of trees and stands, and more reliable predictions of future growth, yield, and quality of forest products. Productivity of forests, both in quality and quantity, varies markedly according to stand density, site quality, tree age, and species composition. Optimum stand conditions for particular management objectives need to be determined for the many combinations of timber types, sites, and conditions found in American forests. Important forest regulation problems involving levels of growing stock, cutting budgets, and rotation lengths must be solved. With better information about the response of forests to various cultural practices, more attention must be given to planning and decision-making problems in order to guide management of large public and private timber holdings.

USDA and Cooperative Programs

A continuing program of studies is conducted at all the Forest Experiment Stations, often in cooperation with industries, other private landowners, State forestry agencies, and forestry schools. Special attention is being given to research in the growth and yield of managed forests and forest plantations. Research is also concerned with mathematical techniques and forestry measurement tools that will permit greater precision and efficiency in practical forest management operations and in forest research. Studies have started on the automation of aerial-photo interpretation. A Pioneering Research Unit in Berkeley, California, established in 1961, is studying basic measurement problems. Nationwide, 9 man-years of Federal scientific effort are performed in timber measurement research projects, and several additional years are devoted to related growth and yield studies in silviculture projects.

Progress -- USDA and Cooperative Programs

1. Growth and yield of trees and stands

Growing stock density in young planted and natural stands is of major concern to forest owners because the characteristics imparted to trees early in life have an important and lasting effect on size and quality of trees, and on timing of thinning and determination of rotation ages. For example, in North Florida in 1935, a slash pine stand 7 years of age, and averaging 3,500 stems per acre, was thinned to 700, 400, and 200 trees per acre, with no thinning as a control. Twenty-nine years after treatment, and with two intermediate thinnings, results illustrate that increased yields will more than pay for the cost of precommercial thinning. They

further show that if the management goal is maximum cordwood yield, a stand of 700 trees per acre, or more, will fulfill the objective over a wide range of rotation ages. If maximum sawtimber and gum yields are the objective, a stand of not more than 200 trees per acre should be retained.

About 2 million acres of pole-size lodgepole pine in Colorado and Wyoming are in need of thinning. If left unthinned, these stands will yield an average of 10,000 board feet of timber per acre worth about $75 at harvest time; if thinned, yield can be increased to 30,000 board feet per acre worth more than $225. Furthermore, the rotation age for thinned stands is about one-half that for unthinned stands. Two kinds of thinning were studied to identify the one that will best stimulate growth of individual trees and stands. Uniform thinning reserved 630 trees per acre, spaced an average of 8.5 feet apart. Crop-tree thinning released approximately 100 trees per acre, spaced an average of 21 feet apart, by cutting openings 16 feet in diameter around each selected tree. Thinnings stimulated diameter growth of the best 100 trees per acre under both treatments and of all trees on the uniformly thinned plots. Height growth and basal area increment were unaffected. Thinning initially reduced total cubic-foot volume increment, but after 8 years, growth was the same on thinned and unthinned plots. Volume in pulpwood-sized trees was increased only by uniform thinning. The uniform method provided earlier stumpage returns and distributed total growth over fewer but better quality stems.

Overdense stands of ponderosa pine saplings occur on thousands of acres of forest land in the West. Past research has shown that these crowded small trees, up to 70 years old, will respond to release through harvesting the overstory of mature sawtimber and thinning the saplings. Current research is now concerned with determining growth rates of these sapling stands for a range of densities from 62 to 1,000 trees per acre. Six years after thinning in central Oregon, competition had already set in at 250 trees per acre, whereas trees were still growing freely at 125 per acre. Since trees of the 250 per acre density averaged only 3.0 inches in diameter, a second pre-commercial thinning would be necessary to maintain maximum growth rates up to the time of first commercial harvest. It was also determined that elimination of brush and other understory vegetation accelerated tree growth by about 30 percent in this forest type.

A spacing study in a slash pine plantation in Georgia was installed to determine the optimum number of trees per acre, and the effects on growth of various arrangements of individual trees. The plantation, now 12 years old, ranges in density from 194 to 1,210 trees per acre. The densities are equally divided between a square (from 6 x 6 to 15 x 15 feet) and rectangular (from 5 x 10 to 7-1/2 x 15 feet) configuration. Diameter growth losses among trees in the closer spacings began to develop at age 5. By age 12, mean average height and dominant height were slightly reduced by closer spacings. For the same number of trees per acre no difference in bole form, live crown form, or growth can yet be detected between the square and rectangular configurations, indicating that trees

within rows need be only half as far apart as the rows themselves. This means that far fewer rows need to be planted, thus offering a considerable reduction in hand- or machine-planting costs, and easier access for the extraction of thinning products.

The main advantages of commercial thinning are (1) salvage of mortality, (2) reallocation of stand growth to fewer, larger, and higher quality trees, and (3) earlier financial returns through thinning. Two thinning experiments in Douglas-fir in Washington, one in 60-year-old stand and the other in 110-year-old stand, suggest that moderate thinning (removal of 25-35 percent of basal area) accomplishes the objectives better than heavy thinning (removal of 40 to 50 percent at basal area). Both moderate and heavy thinning halved mortality losses compared to unthinned stands, and shifted growth to fewer trees. However, heavy thinning was accompanied by important growth losses in the years immediately following thinning.

In Missouri there has been a 46 percent increase in the area of pine stands since 1947 and the acreage in pine sawtimber stands has tripled in the same period. Many of these stands need to be thinned if the full yield potential is to be realized. A detailed study has shown that a 30-year-old shortleaf pine stand thinned to 70 square feet of basal area per acre gave better overall growth and yield than another higher-density stand. The value of products removed varied from $66 per acre in the high-density stand to $93 per acre in stands cut to 70 square feet.

The same study indicated that thinning from larger trees from the upper crown canopy permits an early recovery of a high proportion of the investment in growing stock, but may eliminate genetically superior trees. A comparison of yields from stands thinned to 70 square feet of basal area per acre, both from above and from below, showed that thinning the largest trees yielded $73 worth of products whereas removal of the smallest trees yielded only $24 worth of products. Both stands grew about equally, but cutting of the largest trees will increase sawlog rotation by about 20 years at current growth rates. Thinning from above may be good short-term economics but poor long-term management. If practiced at all, it should be limited to one thinning early in the rotation.

In mixed forests decisions on which species to favor requires knowledge of how their performance compares on specific sites. Records from 108 permanent plots in the western white pine type in northern Idaho were analyzed to develop equations that permit prediction of average dominant-codominant height of any one of five associated species from the site index of western white pine. Other equations were developed to estimate white pine site index from known age and height of the alternate species. This information will assist the forest manager in developing needed species-preference guides for thinning and planting operations on sites capable of growing western white pine.

Site productivity estimates for young Douglas-fir are basic to management planning and research in this most important forest type. The accepted estimation procedure depends on site index (height over age) curves. New curves developed by the Weyerhaeuser Company were compared with standard curves, using data from remeasured plots. The new curves were superior. Results suggest that the standard site curves on which current yield tables were based may seriously underestimate site productivity in young stands, with corresponding errors in yield estimates.

Our ability to make wise decisions on appropriate silvicultural treatments in even-aged beech-birch-maple depends upon information on trends in stand development and the variability in tree behavior within a stand. Although available yield tables provided us with some information on average trends in the development of beech-birch-maple, we lacked data on within-stand behavior. A study in even-aged, essentially pure stands up to 50 years old quantified the changes over time in the variability of tree diameter and tree height, and the distribution of crown classes, size classes, and quality classes for sugar maple, yellow birch, and paper birch. In some instances, results were related to broad site classes. Results of this study add considerably to our knowledge of stand behavior, and will be used in future attempts to develop new silvicultural guides for beech-birch-maple forests.

A number of tables have been published setting forth predicted per-acre wood yields for planted slash pine according to age, site, and density. Diameter characteristics of individual trees in these plantations have not been previously available. A study recently completed in Georgia provides a method for determining diameter distributions. Such information will be useful for foresters and land managers because (1) the number of merchantable stems for pulpwood or sawtimber can be forecast without the expense of an inventory, (2) the number of trees large enough for naval stores production can be easily and inexpensively ascertained, (3) optimum spacings for multiple-product combinations showing the greatest returns can be determined, and (4) harvesting costs for stands of various ages, site indexes, and stand densities can be evaluated.

2. Forest measurement

Measurement of trees, stands, and forest products is a large part of the workload of many forestry enterprises. Consequently we continue to seek ways to reduce the time and cost of measurements. The most notable new development in this field is a system of sample tree selection, measurement, and computation which is undergoing testing and development in several parts of the country. This system involves (1) a method of selecting sample trees in proportion to value or size (probability proportional to prediction or 3-P sampling), (2) optical dendrometers to measure upper stem characteristics in standing trees, and (3) high-speed computers to calculate volumes, values, and sampling errors. The system eliminates

the need for conventional volume tables. Several scientific and professional papers within the past year have elaborated on the application of 3-P sampling, or on improvements in the use of optical dendrometers. It is likely that we will see much more development work to adapt the new tree measurement system to various timber types and situations throughout the country.

Within the past year aids have been developed to speed the use of the optical dendrometer, and to reduce the chance of error. The Southern Forest Experiment Station developed an aiming device to facilitate sighting, a transit-mount to insure stable instrument settings and fine adjustments, a field chart to translate instrument readings into tree diameters, and tables to reduce trigonometric calculations for determining tree height or for setting the sights to a given height. The Pacific Northwest Station developed a slide rule to make possible quick field checks of dendrometer readings. The slide rule will save money in field work, and permit more rapid detection of the need for instrument adjustment.

Our ability to create more and better aerial photography has been enhanced by new development in films, cameras, and flying platforms including orbiting satellites. The use of the infra-red and other non-visible portions of the electro-magnetic spectrum show promise of providing still more information about the earth's surface and about the organisms growing on it. All of this points up the need to speed the rectification and interpretation of the photographs. Development work now underway in California and elsewhere demonstrates the feasibility of using computers and computer-related equipment to (1) reduce aerial photos to digits based on the brightness of individual objects, (2) remove tilt from the photo, and (3) create a digital steroscopic image in the memory of the computer. Additional development work is needed on computer programs and statistical procedures that will translate this vast amount of data into information useful to foresters and other land managers.

A measurement problem of long concern to forest researchers involves the interpretation of repeated measurements through time on the same trees or stands. In the past, multiple remeasurement data has often been analyzed by regression techniques, ignoring the fact that 10 observations on each of 5 trees are neither conceptually nor statistically equivalent to 50 separate observations. Since measurements on the same individual are correlated, the usual regression techniques will not provide correct tests of significance or probability statements. An analytical method for remeasurement data is proposed in a Forest Science paper from the Northeastern Station, based upon the assumption that each experimental unit provides an independent estimate of the population regression line.

The selection of an appropriate probability distribution is a basic step in statistical analysis. However, none of the common distributions are applicable to certain variables encountered in forestry research, such as tree diameter in an uneven-aged stand. Based upon available empirical data on tree diameter, the J-shaped or negative exponential distribution is derived in a second Forest Service paper from the Northeastern Station. Expressions are given for the cumulative distribution, probability density function, mean, and variance; also, the conditional distribution, mean, and variance. These results should prove helpful in analytical problems involving tree diameter and similar variables.

3. Management planning procedures

The Georgia Forest Research Council invited scientists and other specialists within and outside the Forest Service to draw together the considerable research and experience available for the management of loblolly and slash pine plantations in Southeastern United States. The resultant guide contains 30 contributed papers, and is intended to identify and forestall many of the problems of plantation establishment, management, and protection that might otherwise confront forest owners. The proper choice of species, sites, and initial spacing are covered, as are such practices as pruning, thinning, fertilization, and drainage. Protection of plantations from fire, insects, diseases, storm, and animal damage are also described. The guide concludes with thorough-going treatment of markets, uses, and other economic aspects of managing slash and loblolly plantations.

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C. FOREST GENETICS

Problem

Genetic improvement of forest trees is one of the most promising approaches to increasing the efficiency of timber production, improving timber quality, and reducing pesticide hazards. Trees bred for rapid growth, good form, desirable wood quality, and pest resistance are urgently needed in reforestation programs. The research job is to determine the degree of inherent variation in important traits, to develop effective hybridization and breeding schemes for improving these traits, and to devise the most efficient techniques for producing and propagating superior types of trees.

USDA and Cooperative Programs

This is a continuing, long-term program of tree breeding. It involves basic studies of genetics, breeding, and plant physiology. Superior phenotypes are selected and bred, and their progenies are evaluated to determine the genetic worth of the selected parents. Outstanding trees are propagated in orchards to produce improved seed. Hybridization is attempted between varieties and species. Any hybrids produced are evaluated, and desirable ones are produced in quantity. Ionizing radiations are used to create new forms of variation. Desirable mutations will be incorporated into useful new tree varieties. Physiological studies facilitate tree breeding by developing methods of vegetative propagation, methods to overcome genetic incompatibility, and methods to assure early and abundant seed production. Other studies seek to explain the physiological mechanisms involved in desired traits like faster growth and resistance to cold, drought, and pests. Research on the identification, classification, and distribution of species and hybrids of forest trees also is included. The application of genetics research to increasing the yield of oleoresin is reported under Naval Stores. The improvement of sugar maples for quantity and sugar content of sap is reported under Maple Sap Production.

The program is carried on principally at three Institutes of Forest Genetics at Berkeley, California; Gulfport, Mississippi; and Rhinelander, Wisconsin. Additional genetics-related research is conducted in Oregon, Georgia, New Hampshire, Vermont, Illinois, Idaho, Florida, Louisiana, and Arkansas. The program involves cooperative research with numerous State agencies, universities, forest industries, and private foundations.

A grant to Yale University is providing information needed to develop pines resistant to the destructive sawflies. Another grant to Purdue University will provide for the basic research needed to propagate superior varieties of black walnut and other high value hardwoods. A new grant to Pennsylvania State University will support studies of the basic mechanisms of resistance of white

pines to the destructive white pine weevil. In addition, grants for basic research in genetics and breeding are in force under Public Law 480 in Finland, Poland, Greece, Italy, Israel, India, South Korea, Taiwan, Spain, and Chile. Some early results from these studies are described in the appropriate sections. The annual scientific effort directed to this research by the Forest Service is about 30 man-years.

Progress -- USDA and Cooperative Programs

1. Inherent variation

The pattern of geographic variation within a species is not only basic to tree improvement but is also of great importance to land managers concerned with the acquisition of tree seed best adapted to their lands. A recent intensive study of slash pine in Florida, Georgia, South Carolina, Alabama, Mississippi, and Louisiana shows that appreciable racial variation exists for most traits. Patterns of variation differ among traits, but usually traits have a gradient in a north-south direction, with a low or a high in the north-central portion of the species range. For example, trees in the north-central portion of the slash pine range seem to be the most rapid growing. These early results are based mainly upon traits such as height, stem diameter, needle length, number of stomata, and resin ducts. As the plantations mature, traits such as volume growth, gum yield, and gum quality will be studied. Pinpointing areas of desirable slash pine types will provide opportunities for forest land managers to increase production efficiency and the quality of gum and wood produced.

An inherently superior strain of slash pine that produces about twice the normal amount of gum has been developed at Olustee, Florida. Now genetic relationships of gum yield to other economically important traits are being studied. High gum yielding trees are found to be fast growing also. For example, the present high gum producing strain will yield about 12 percent more volume of wood than normal trees. This was an unexpected bonus of the naval stores research and this interrelationship of gum yield with growth should facilitate attempts to improve growth rate even more. There is little or no correlation between gum yield and stem straightness or branch thickness. This suggests that efforts to combine superior stem and crown form with high gum yield should be fruitful. Gum yield and specific gravity seem to be negatively correlated to a slight and apparently unimportant degree. There is still a need to determine the mode of inheritance of gum yield and other important traits. A knowledge of the number of genes involved and the linkage of traits will form the basis for faster breeding of multipurpose strains of slash pines.

Seed from the wrong source can eliminate any chance of profit from southern pine plantations. This is indicated by a provenance test of loblolly pine that has now gone through one pulpwood rotation. At Bogalusa, Louisiana, where the tests were made, local seed was best at 35 years. The mean annual increment in rough cords

per acre was 2.70 for the local source compared with 1.28, 1.17, and 0.54 for the Texas, Georgia, and Arkansas stocks respectively. Yields of these latter sources may have been higher had they not been partially overtopped by the faster growing local source. The Georgia stock was most susceptible to fusiform rust-infection. At the end of the pulpwood rotation, age 35, Louisiana and Texas sources were preferable to Georgia and Arkansas sources for use in areas of serious rust hazard.

Reliable evaluation of trees from different sources requires many years, but results from another provenance study of longleaf pine planted in Rapides Parish, Louisiana, suggest that correlations of rainfall and temperature patterns with tree growth may provide a means for preliminary delineation of seed collection zones. Such correlations would greatly reduce the number and the cost of provenance studies.

The white-pine weevil is the most serious obstacle to effective management of white pine in the Northeast. A year ago research determined that resistance of white pines to this insect is genetically controlled. New research results are now providing more efficient selection and testing criteria. At the site of natural injuries such as those caused by the white-pine weevil, a compound, leuocyanidin, accumulates and seems to be associated with resistance to insect entry. In other studies, it was found that many weevil-resistant trees formed resins that did not crystallize during weevil attacks. These results provide promising leads for developing reliable criteria for selection of weevil-resistant individuals in the tree-breeding program.

In much of the Midwest, a problem is to find white pines adapted to the climate and soils. Results of a 6-year-old study in Ohio, Indiana, Illinois, Kentucky, and Iowa showed the best source of white pine seed for these States is the mountains of Tennessee, Georgia, and North Carolina. From these areas seedlings planted in the Midwest grew 2 to 3 times faster than white pine seedlings from the Lake States, the Northeast, and Canada. More work is needed to pinpoint the best sources of white pine seed and to develop strains of white pine specifically adapted to the environment of the Midwest. Opportunities are good for growing white pine in the Midwest because the white pine blister rust and the white pine weevil are not serious problems.

The genus Pinus is economically the most important of the world conifers, yet much information on the world distribution of the 94 pines was scattered in many different sources. This information is now summarized in a Department of Agriculture publication with 64 maps and explanatory notes. Published sources of information were supplemented by having specialists review preliminary versions of all the maps. More than 500 references from the world literature are cited. This publication will greatly facilitate scientific work on pines throughout the world.

Many years are required to evaluate growth and survival among geographic or altitudinal races of Douglas-fir. Survival differences due to race are seldom displayed in the first quarter century, yet high survival is necessary for high volume yields in long rotations. A 50-year-old provenance study of Douglas-fir is showing that local races appear destined to produce more volume than non-local races primarily because the local races have higher survival after 50 years. Some introduced races might outproduce local races at short rotations on protected sites but local races, because of higher survival, would have greater volumes after a number of decades.

The most obvious fault of sweetgum for lumber manufacture is the warping thought to be related to "interlocked grain." Interlocked grain is caused by spiral grain that alternates repeatedly between a right- and a left-hand spiral around the tree. Recent studies of 225 sweetgum trees growing in Mississippi, Florida, Georgia, North Carolina, South Carolina, and Virginia indicate this undesirable feature of sweetgum may be genetically controlled. The severity of interlocked grain was greatest at stump height, decreased to a minimum around 10 to 20 feet above the ground and then increased slightly toward the upper part of the stem. But there were striking differences among trees growing together under similar environmental conditions. Thus, choice of seed parents which have straight grained wood may eliminate some troublesome problems in processing sweetgum lumber and veneer.

Each year Forest Service geneticists find new sources of timber trees having inherent pest resistance. For example near Watersmeet, Michigan, 29 seed sources of jack pine are found to differ in susceptibility to the needle cast fungus (Hypodermella ampla). At the end of the tenth growing season the least susceptible source, northeastern Minnesota, had only about 25 percent infection compared with 95 percent for trees from the Lower Michigan source. Since these differences remain constant from year to year and from environment to environment, they are considered to have a direct genetic basis. From these provenance tests selected trees will provide breeding material for geneticists to develop strains of jack pine resistant to the needle cast fungus.

Interagency coordination is advanced by a new publication summarizing all forest tree improvement research in the Lake States. Information on public and private forest genetics research is listed by species and kinds of research. These summaries provide a basis for planning efficient forest genetics research without duplication of effort.

2. Hybridization

Natural hybrids among southern pines are resistant to diseases that attack one parent species. Hybrids of loblolly and shortleaf pine are apparently resistant to southern fusiform rust, a serious disease that attacks loblolly pine. A major

problem is to identify these hybrids in natural stands. Intensive studies of natural hybrids and hybrids of known parentage revealed ways to use combinations of vegetative characters to separate hybrids from parents in natural stands. Good separation was obtained with scatter diagrams of needle length, sheath length, type of sheath, length to width of axillary scale, and twig color. The environment under which the trees grow greatly influences the vegetative characters used for separating hybrids from parents. Environmental fluctuations of vegetative characters indicate the desirability of evaluating genetic-environment interactions when searching for inherently superior strains. Environmental modifications are often large enough to mask single-character differences. But, combinations of characters are useful. This knowledge provides an effective way to identify and select from natural stands hybrids that can be used in breeding for strains resistant to fusiform rust.

Accurate descriptions of man-made pine hybrids are necessary to permit foresters to recognize these trees as such. Botanical descriptions of 40 first generation pine hybrids are recorded in a new publication. Performance of these hybrids, now growing in California, will be published later.

The relation of two important western true firs--noble and California red fir--has been a puzzle to foresters and botanists for many years. Identification of these trees has been especially troublesome to foresters in southwestern Oregon where both occur along with an abundance of individuals intermediate in character. Reciprocal crossing of California red and noble fir produced abundant putative hybrid seedlings intermediate in cotyledon number between the two parent species. This result strongly suggests there is no genetic barrier to crossing of the two species where ranges overlap. The highly variable southwestern Oregon populations, referred to in the past as Shasta red fir, may therefore represent hybrid swarms resulting from large-scale natural crossing of these two species. The absence of crossing barriers and the wide genetic variation in the hybrid swarms offer excellent opportunities for developing inherently superior firs adapted to specific environments.

3. Methods used in tree breeding

Progeny-testing forest trees for seed certification purposes requires many years, standard varieties, and uniform testing methods. A recent paper describes the problems relating to establishment of progeny tests for tree seed certification. Responsibilities of the producer, the certifying agency, and the buyer are stressed. Tree seed dealers must approach the problem of testing from a slightly different viewpoint than the majority of crop breeders. At present there are no standard varieties against which to test new forms, nor is there any established system of varietal trials. Each test must be designed to meet its own specific objectives and must run many years for complete evaluation. Some characters of economic importance require tests of 20 years or longer; few traits can be evaluated in a

period as short as 5 years. But the demands for improved material are so great that land managers will probably accept preliminary estimates at younger ages as indicative of future gain and proceed on that basis.

A major obstacle to hand pollination of large yellow-poplar trees is the difficulty and great hazard involved in climbing the long clear stems and working in the brittle crowns. In North Carolina, using a rifle for shooting twigs from the top of selected trees and then grafting these twigs onto seedlings in a greenhouse shows great promise for speeding the genetic improvement of this species. Soon after the grafts are made, flowers bloom and are pollinated by hand. Flowers blooming the first season after grafting are from flower buds formed on the tree the summer before. Grafts do not flower the second season. Just how soon yellow-poplar grafts will resume flower production is not known. Further development of this method holds considerable promise for reducing the cost of genetically improving yellow-poplar.

A major problem with controlled pollinations is the low seed set, often obtained with conifers. In Wisconsin, a study showed that irradiated pollen may increase seed set of pollinated white spruce. Female flowers of white spruce were pollinated with pollen given 0, 400, 600, and 800 roentgens of gamma radiation. Stimulation of seed set was most pronounced at 600 roentgens of radiation. Observed seed viability suggests that the dosage for 50 percent death is higher than 800 roentgens. Further investigation of this very promising use of gamma radiation in forest genetics could provide a means to increase the seed set of other control pollinated conifers. Other studies are investigating the effects of pollen irradiation on embryos, seeds, and seedling development.

In central Louisiana, observations showed no relationship between date of maximum flower receptivity to pollen and cone maturity in longleaf pines. Time requirements for seed development on individual trees were found to be constant but varied as much as 4 weeks between trees. It cannot be assumed that longleaf pine cones ripen in the same order that female strobili becomes receptive to pollination. However, cone maturity dates for a single year can be a guide for the order of collections in subsequent years. Seed dealers, nurserymen, and tree breeders can use this information to plan collection schedules in seed orchards and seed collection areas.

Microchipping is a rapid and reliable technique for screening trees thought to be superior gum yielders. New information from Olustee, Florida, shows that the cost of genetically screening large numbers of trees can be reduced by using six midseason microchips instead of full season microchipping. Yields from two biweekly microchips in May, July, and September had a correlation coefficient of 0.76 with yields from standard faces on the opposite side of the trees. In a second trial yields from six successive biweekly microchips in June and July were also correlated (R=66) with full-season standard face yields. Standard face yields are easily estimated by use of a table of ratios of standard face yield to microchip yield and diameter of the trees.

Another inexpensive and time-saving method for collecting small samples of oleoresin has been used for 2 years at Gulfport, Mississippi. The screening of large numbers of trees thought to be resistant to the southern pine beetle requires the analysis of resin components. The method called "mini-tap" consists of boring a hole about 1 inch in diameter into the tree with a carpenter's brace and bit and screwing small bottles directly into the hole. This rapid method prevents loss of volatile gum components, enhances gum flow by retarding crystallization, and is inexpensive.

Grafting scions of superior trees upon seedling stock is a common way to establish clonal seed orchards of pine. But there are still many problems in grafting pines. In Italy, results from research supported by Public Law 480 provide ways to increase the efficiency of making pine grafts in seed orchards. The investigations showed that cleft grafting on the top of the stock was twice as successful as veneer side grafting. Scions for cleft grafts should be slightly larger than the stock in order to get a better correspondence of homologous tissues. Without this correspondence of tissues, callus may form between the scion and the stock and result in eventual death of the scion. Sheltering the new grafts, grafting in the summer, and reducing the time between the collection of scions and the grafting process greatly increase the number of successful grafts. Biochemical investigations indicated an increase in grafting success when the scion and stock had similar enzymatic patterns. These results will help to improve the efficiency of establishing clonal seed orchards of pine in the United States.

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D. TIMBER-RELATED CROPS

Problem

The forests of the United States produce a number of timber-related forest crops, some of which are sources of important industries in different parts of the country. These products include naval stores, maple sap, Christmas trees, and a group of minor crops composed of edible, medicinal, and decorative materials. Some of these crops, independently or in combination with timber production, greatly enhance the total income of forest owners. These crops also provide a ready cash income which is not easily obtainable from periodic timber harvests. Many of the minor forest crops provide supplemental income to individuals in low-income areas. The research problem is to determine the potentialities of these timber-related forest crops and to develop the most efficient methods for their production.

Another important area of research is to develop better types of trees and cheaper and more effective methods for establishing, maintaining, and improving shelterbelts on the Great Plains. Shelterbelts and other special-purpose tree plantings ameliorate the local climate and improve the quality and appearance of suburban and rural environments.

USDA and Cooperative Programs

The present program of Forest Service research in timber-related crops includes a project in naval stores production and related tree improvement research at Olustee, Florida, a project in the production of maple products and related tree improvement research at Burlington, Vermont, a project on production of Christmas trees and other timber-related crops from Appalachian forests at Berea, Kentucky, and a small amount of research on Christmas tree production conducted as part of silvicultural and genetics projects in Michigan, California, and elsewhere. Shelterbelt research is located at Bottineau, North Dakota, and Lincoln, Nebraska.

The naval stores research includes fundamental studies of the physiology of oleoresin flow and applied research on the improvement of gum extraction techniques. The extraction phase of the research will be coordinated with equipment development research in the forest engineering project of the Forest Service at Auburn, Alabama. The research on maple sap production involves studies of physiology of sap flow, maple orchard management, and the development of strains with higher sugar content and sap yield, all in cooperation with the University of Vermont.

Research in shelterbelts includes the selection and breeding of trees for better form and greater resistance to the severe climates. It includes techniques of planting and cultivation leading to higher survival rates and more rapid juvenile growth. Methods of maintaining the vigor and density of the shelterbelts over long periods of time are also under study.

Research on Christmas tree production includes the development of types of trees better adapted to Christmas tree use, as well as intensive cultural methods for diverse species, sites, and markets. Research on the miscellaneous timber-related crops such as greens and medicinal plants centers on ways to increase the supplemental income to forest owners.

Forest Service research in these fields is closely coordinated with the naval stores and maple sugar processing of the Southern and Eastern Utilization Research and Development Divisions of the Agricultural Research Service. Some phases of the Christmas tree and maple sap production are studies by State agencies and universities often in cooperation with the Forest Service. Shelterbelt research is coordinated with work of the Crops Research Division and the Soil and Water Conservation Research Division of ARS and with work of the State Experiment Stations through the Windbreak Research Committee of the USDA, and Research Subcommittee of the Forestry Committee of the Great Plains Agricultural Council.

A grant to the University of Vermont provides for basic research of the enzyme systems responsible for the interconversion of sucrose, starch, and hemicellulose in selected sugar maple trees.

The annual Federal scientific effort devoted to the research by the Forest Service is 16 professional man-years.

Progress--USDA and Cooperative Programs

1. Naval stores

Interest is growing in the new technique of using sulfuric acid paste, rather than a water solution of the acid, to stimulate and prolong gum flow. A bark hack with 1.25-inch blade is commercially available to put on the wider streak needed. Also, a paste applicator which enables the chipper to apply the paste in precisely the right place and in the right amount has been developed.

Substantial cost reductions and profit increases result from the use of paste. Since the gum continues to flow for as long as 4 weeks with only a small reduction in yield, chipping labor costs could be cut by as much as $4 per barrel of gum. The value of the gum is increased because better grades are obtained. With paste, the acid does not run down the face and the grade of gum produced is higher. The top grades of gum, WW and WC, are worth $2 to $4 more per barrel than lower grades.

Additional cost reductions are possible by the use of larger cups. The normal size 2-quart cup must be emptied every 3 to 4 weeks. Research has shown that containers as large as 10-quart buckets can be used without appreciably lowering the quality or turpentine content of the gum. With larger containers the number of collections could be greatly reduced, with cost savings of up to $2 per barrel possible.

It is estimated that industry-wide use of these new techniques could result in net savings ranging up to $5 million per year. Further developments are in sight that can increase returns still more. A strain of slash pine has been bred which will produce about twice as much gum as woods-run trees. Eighty acres of seed orchard of this strain have been established in cooperation with State and private organizations. Substantial quantities of seed, 10 to 15 million per year, will be available in a few years.

2. Maple sap production

The development and use of superior trees should be an important factor in the future of the maple sugaring industry in the Northeast. Superior trees, developed through selection and breeding, can reduce production costs through increased production of sugar per tree and per man-hour of labor. Selection of trees with high sugar content and high sap yield is going forward with the help of many groups in the Northeast. Meanwhile, research is proceeding on basic techniques for propagation and breeding.

A major difficulty in sugar maple tree improvement research has been the production of clonal material for testing. This problem has now been largely overcome by the development of air-layering and rooting techniques. Procedures and materials are described in two recent publications. Air-layering response varies among individual trees, times of year when treatments are applied, widths of girdles used in wounding branches, and treatment positions on the branch. Although mortality of the air-layered cuttings over the first winter may be high, survivors grow well. Rooting percentages of 40 to 60 percent are obtained after 8 to 10 weeks in a propagation chamber. Some difficulty is experienced over-wintering these rooted cuttings, and additional research is needed before the methods are commercially useful. Yet, adequate stocks of clonal material can be provided for research purposes.

One of the essential conditions for hand pollination of sugar maple is that the stigma must be in receptive state when the pollen is applied. Studies at Burlington, Vermont, found five stages of stigma receptivity based upon morphological characteristics and supplemented by observations on pollen germination and pollen tube growth. The appearance of the female flower was described at each of these stages. As a result of this research, greenhouse and field pollinations may now be made with maximum success.

3. Shelterbelts

Shelterbelts have been important in the conservation and development of the Great Plains since early settlers first set out wild tree seedlings in the mid 1800's. The largest number of plantings began in 1935 with the Prairie States Forestry Project. These plantings of over 200 million trees and shrubs have served well to protect

homes and farms. But today the effectiveness of these older plantings is reduced by sod encroachment and by loss of trees by drought, disease, insects, and crowding. At Lincoln, Nebraska, research is showing how to renovate these old windbreaks to restore their effectiveness. Ordinary farm machinery and tools are used to remove rows of dying and diseased trees, replace damaged trees with new plantings, and release vigorous trees so their foliage can become dense and more effectively slow the wind. In old windbreaks some soil, compacted by grazing farm animals, must be broken up and left bare over the winter to collect as much snow and moisture as possible. Techniques for renovating and applying "first-aid" to these old windbreaks are described in two new publications that are readily available to landowners.

Current information on the whole field of shelterbelt establishment and culture has been summarized in a series of seven how-to-do-it leaflets prepared in cooperation with the Soil Conservation Service and the Extension Services. These 8-page leaflets use easily understood diagrams and informative photographs to tell prairie landowners how to use trees to protect land and crops, how to select tree and shrub species, how to arrange and space trees and shrubs, how to prepare land and plant trees, how to maintain new tree plantings, how to protect them from damage, and how to manage established plantings.

Pines and junipers give greater winter effectiveness to shelterbelts than deciduous trees and shrubs. Ponderosa pine has been planted for many years and has been a valuable conifer for windbreaks. But survival is often low. Also, shape of the crown, density of the foliage, growth rate, and resistance to pests vary with races and strains. In North Dakota, 25 to 30 years of observing ponderosa pine from eight geographic areas has revealed wide differences in foliage density, branch habit, and growth. For North Dakota plantings, eastern Montana is a desirable source of seed for ponderosa pine. A new study is just getting underway using ponderosa pine seed from 80 sources ranging from Canada to Arizona and including the Dakotas, Montana, Wyoming, and Nebraska. These trees will be evaluated for inherent resistance to drought, frost injury, pest resistance, and foliage density. Already some apparently superior trees have been located and are now undergoing further tests. Studies of junipers used for shelterbelt plantings show great differences among trees. These studies provide researchers with a sound basis for genetically improving Great Plains planting materials for use in windbreaks on recreational areas and for highway protection and beautification.

4. Other

Genetic forms of timber trees are often valuable for protective and aesthetic plantings near airports, highways, industrial sites, and urban and suburban areas. In Georgia, a new variety of sweetgum recently found may be valuable for these uses. This bush-like tree, between 8 and 9 feet tall, was found growing in the open near an old house site. No seed heads or flower buds were found but leaves, buds, and

leaf-scar characteristics left no doubt that it was a modified form of the native sweetgum. Apparently the bushy appearance is caused by a pronounced short shoot habit. Twigs only 3 inches long are 5 to 10 years old. There is no central stem and the many branching shoots indicate none of the shoots are able to become dominant. This tree had been planted some 20 to 25 years previously by a farmer who removed a root sucker from a similar tree growing in the woods nearby. In addition to its possible value for aesthetic and protective plantings, this dwarf sweetgum opens vistas for research in tree physiology, morphology, and possibly genetics. Physiologists may find this dwarf tree useful in studies of the effects of growth regulators, especially the gibberllins.

Christmas tree growers are interested in a hybrid pine developed in the course of forest-tree improvement research at Berkeley, California. The tree is a hybrid between two races of lodgepole pine and has some desirable traits for use as a Christmas tree: good form and color, relatively rapid growth, and early production of persistent cones. In 1964, the California Christmas Tree Growers financed a series of crosses between these two varieties of lodgepole pine. The trees proved to be easy to cross and showed none of the genetic barriers to crossing that often occur between different species. We know very little about the growth of this hybrid outside California. The Forest Service and several cooperators have made plantings in the East and Pacific Northwest. As additional seed becomes available, we plan more extensive tests of the suitability of this hybrid for regions other than the low-elevation California climate in which it was developed.

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II. WATERSHED, RECREATION, AND RANGE RESEARCH

A. FOREST SOIL AND WATER RESEARCH

Problem

All of the major rivers of the United States have headwaters in forests, associated rangelands, or alpine regions. To derive the greatest benefits and protection from these headwater areas, improved knowledge of the management of watersheds and streams is needed. More than half the waterflow of the country originates in such areas. The management of these areas is a major factor in determining whether this waterflow is beneficial or harmful, whether it is a well-regulated, sustained flow or erratic with alternating floods and dry channels, and whether it is clear or silt-laden. Recent estimates of water demands indicate an increase from the present 325-350 billion gallons per day to the 450-500 b.g.d. range by 1980--a 40-percent increase. The most logical place to look for additional supplies of high-quality water, or to improve timing of streamflow, is in the headwaters. At the same time, there are constantly increasing pressures to use watershed lands for a variety of other products and services. Additional research is needed to determine how best to adjust these several uses to give the necessary protection and development to soil and water resources.

USDA and Cooperative Programs

This work includes basic and applied research into the relationships of soil, climate, vegetation, and water and the development of methods and techniques to: (1) increase water yields or improve the timing of such yields under a variety of climatic, soil, geologic, vegetative, and topographic conditions; (2) give adequate protection to soil and water resources while forest and related range lands are being used for timber production, grazing of domestic livestock and big game, wildlife habitat, mining, and forest recreation; (3) rehabilitate forest and related range land watersheds that constitute sources of damaging flood runoff and sediment; and (4) aid forest soil development and improvement.

Eighty-two (82) man-years of effort were expended by the Forest Service on this research during the past year. This is the first year in which researchers only in grade GS-11 or above were counted.

Progress--USDA and Cooperative Programs

1. Water Yield Improvement

Research in the improvement of water yield is conducted in the different terrain, climatic, and forest vegetational complexes throughout the Nation. The purpose is to explore the opportunities for improving the amount and/or timing of water yield through manipulation and management of the Nation's forested and related range and alpine watersheds. Water yield improvement research is being done in (a) alpine snowpack zones of the West, (b) forested snowpack zones of the East and West, and (c) in nonsnow forest areas. Research results are discussed under these subdivisions.

a. Alpine snowpack zone. The alpine zone includes the area above timberline. The climate is cold, and winds move the snow about continuously. Snow cover is seldom over 2 feet deep except for protected pockets in ravines or behind obstructions where the snow may drift to depths of 30 feet or more. The drifts melt slowly and last well into the summer, maintaining streamflow long after ordinary snow accumulations and lower elevation snowpacks have melted. There are approximately 5 million acres of alpine area in Colorado and Wyoming. Ten to twenty percent of these alpine acres have snowfields that remain during the summer months and contribute to summer streamflow. Flow regulation should be very important to those water users served by direct diversion from streams above reservoirs.

The importance of the alpine snowfields was demonstrated by a study in the Front Range of Colorado, lying along the Continental Divide. Here it was found that 3.75 acre-feet of water were released during July and August for each acre of snow present at the end of June. Although the snow did not cover the whole alpine area, an average of 6 inches of water over the whole area was released. When the amount of snowmelt was compared to the amount of runoff for the period--measured downstream--the correlation was very high. In one drainage area mostly in the alpine zone, snowmelt during July and August accounted for 95 percent of the total runoff for that period.

One of the goals of alpine snow research is to induce deep drifting and thereby increase late-season streamflow. The benefits of using artificial barriers--usually snow fences--has been demonstrated along main ridge lines. The most recent study in central Colorado tested the possibility of increasing additional accumulations of snow in natural terrain depressions. At three of six test sites, fences increased snow depth appreciably and snowfields persisted longer than usual. At other sites, snow depths were increased close behind the fence but were decreased farther downwind with no increase in the amount of snow caught. The reasons for the variable effects are not certain but appear to be related to terrain features, wind direction, and amount of turbulence.

Fences 9 feet tall designed and built for the experimental work have been costing about $5 per lineal foot.

In a snow fence height study on three small windswept watersheds near Laramie, Wyoming, lee drift-water content appeared to be a function of the logarithm of total fence height (6, 8, 10, 12, and 16 feet). The distances from the fence to the maximum drift depth and to the beginning of the drift were both directly related to fence height. But drift length and snow density were apparently not influenced by fence height.

The other aim of alpine snow research is to reduce snow avalanche danger. It was recently determined that 80 percent of all avalanches ran during storm periods. As the increases in winter sports activities and winter travel have increased the hazard of avalanche destruction to life and property, it would be expedient to curtail such activities during storm periods. There are some 116 avalanche paths along the four major highway passes and the one major mining area in Colorado. Approximately 220 avalanches per year have been recorded on these paths and there has been an average of two fatalities per year to this time.

b. Forested snowpack zone. Below the alpine area lie the forested and brush watersheds which accumulate snow and supply much of the streamflow of the western mountains and in the north and northeastern sections of the country. In the West, excellent opportunities prevail for improving water yields from this zone through management of the forest vegetation. Annual precipitation averages 30-50 inches of water, 45 percent of which appears as runoff. Preliminary studies of cutting patterns and other forest management practices which reduce interception and evaporation losses and increase the snowpack indicate possible increases in water yield as much as 4 inches (20 percent). Little is known about the effect of various forest densities, cutting patterns, slope direction, climatic characteristics, etc. upon snow accumulation, ripening, and melt.

How little is known about snow interception, for example, is illustrated by the contrasting conclusions from different snowpack studies.

Certain estimates of water loss due to interception of snow by conifer crowns and subsequent evaporation have been so large that they were questioned by other trained observers. However, an analysis of the physical and climatological processes involved indicates that these large amounts may be quite reasonable. The peculiar geometry and energy-absorbing surfaces of the conifer canopy create great differences in evaporative energy between this intercepted snowfield and one on open, level ground. These differences appear sufficient to account for considerably greater losses from intercepted snow.

On the other hand, measurements made in Colorado found no increase in total snowpack due to cutting. This indicates that intercepted snow did not vaporize at a faster rate than snow that fell in openings in the forest. But alternate strip cuttings did result in snow redistribution and about 4 inches more snow accumulated in openings than under trees at the Fraser Experimental Forest. This redistribution is favorable to increasing the proportion of snow converted to streamflow.

An increase of streamflow of 25 percent was demonstrated from harvesting one-half of the merchantable timber in a sale in Colorado. An increase of 3 inches of runoff--80,000 gallons per acre of watershed--was obtained. New water supplies are now being offered to municipalities in the South Platte area at 50¢ per 1,000 gallons, delivered to the city main.

Since the development of snow surveying 56 years ago man has sought for a means of measuring internal snow density without destroying the sampling site through sample extraction. Such a system has not existed until studies of new systems were begun at Central Sierra Snow Laboratory to develop methodology for measuring internal densities of snowpacks. Five nuclear systems were used to measure internal snow density. One system is much superior to anything else ever developed. With it one may accurately measure snow density in increments of one-half vertical inch. The system consists of a 5 millicurie Cesium-137 source probe and a sodium iodide crystal detector probe, each of which is moved in a separate aluminum access tube located at a desired interval up to 36 inches apart. The probes are raised and lowered as a unit. The gamma energy from the source pulses through the snow to the detector and from there to the electronic sensing elements where all energy except that at the same level as that emerging from the source is eliminated. Thus, counts are obtained from energy which has gone directly through the snow in a straight line. This energy goes to a scaler-ratemeter for counting and from there to a chart recorder. The probes may be raised at a rate of 1 foot per minute through the snow.

Density determination to within 2 percent accuracy may be made in vertical increments of one-half inch. This unit can be modified for use as a remotely operating, telemetered system. This system provides for the first time the ability to study avalanche hazard buildup, potential flood situations created by rain falling on a snowpack or by melting snow.

The system will be the heart of any serious snow research and will be invaluable in study of glacier makeup and in study of avalanche hazard buildup. It can be telemetered and when remotely operated can be used in snow survey and flood forecasting. If imaginatively used this tool can result in better snowmelt forecasts which in turn will permit better reservoir regulation. This will mean better water management and less need for reservoir storage space. Its use in flood forecasting from rain-on-snow floods can result in increased warning time, permitting removal of people and property from flood paths hours before current methods indicate a need for such removal.

A group of 163 experimental snow courses was studied intensively to evalute the effect of more than 20 site conditions. The results have led to new recommendations for selecting representative snow courses on mountain basins. This should make it possible to reduce the number of snow courses in future years. Over 2,000 are now in use in the Western United States. And in conjunction with the use of satellite pictures, it should be possible to make better estimates of expected streamflow for the next summer's irrigation.

In watersheds where low flow augmentation is needed for pollution abatement or other purposes, the conversion of open lands or hardwood forests to conifers is not recommended where ground water forms the major source of late-season flows. In sand-drift aquifers in the Lake States, winter and spring precipitation provide most of the annual water yield. Pine plantations with crown densities of over 80 percent had 1.8 inches less water in the snowpack than neighboring deciduous forests. Ground-water recharge during the melt period was in direct proportion to the snowpack. The difference in snowmelt recharge was a major factor in the lesser water yields measured under pine forests.

Runoff records covering a 23-year period for a reforested watershed in central New York were compared with those of a nearby agricultural watershed. It was found that a combination of open and reforested areas would be advisable for the best distribution of spring runoff. Recently developed analysis techniques revealed that runoff during snowmelt periods is gradually concentrated in a shorter time following reforestation of open lands. There is also a gradual desynchronization with runoff from the agricultural watershed so that concentrated snowmelt runoff comes increasingly later in the season in the years following reforestation.

Records show that a remarkably steady flow of between 0.006 and 0.025 area-inch of water per day leaves the Hubbard Brook Watersheds in New Hampshire in spite of the fact that winter precipitation is tied up in snowpacks up to 6 feet deep and air temperatures are often continuously below 10°F. Measurement of soil temperature profiles and estimates of soil thermal conductivity have led to the conclusion that groundmelt of snow can account for these sustained winter streamflows. Heat conducted from within the soil to the bottom of the snowpack causes the snow to melt.

In the Driftless Area of the Lake States along the Upper Mississippi River, recent studies indicate that the flow of springs is closely related to the flow of streams between storm periods. By measuring the flow of a few springs in an area, information on ground-water discharge is obtained more easily and efficiently than by streamflow record analysis. Ground-water discharge, or base flow, is the water that keeps streams flowing between storm periods and its steadiness is an important factor in trout stream management. The studies on the Coulee Experimental Forest are now showing how springflow reacts to weather variables. Percolation of snowmelt and early rains bring about the primary rise in springflow for the year. Depletion takes place throughout the summer with only small amounts of recharge. Short-term fluctuations in springflow result from changes in atmospheric pressure, flow decreasing with an increase in pressure, and vice versa. This influence is more pronounced in the dormant season than in the growing season.

The use of computers makes possible much more complicated water analyses than heretofore. Large multiple regression analyses, for example, were just too cumbersome to handle by desk-type calculators, but are now in general use. Progressing from the conventional regression analysis, newer multivariate statistical methods have been advocated and these were tested at Berkeley, California. The combination of several methods has been recommended for initial analysis on multifactor hydrologic problems. This development should have widespread benefits in improving evaluations of the many interacting variables which are nearly always involved in hydrologic and forestry problems. An easy-to-use program written in Fortran IV and MAP has been developed.

Using heat pulse methods, sap movement was found to occur throughout the entire year, including winter. During the spring, when soil moisture is plentiful, sap movement is very responsive to weather factors, varying between zero and the maximum achieved during warm, partly cloudy days. Summer and fall velocities reflect a combination of soil moisture availability and transpiration stress--a weather factor. But in winter, sap movement shows little relationship to weather factors; it appears to be related to wood moisture deficits.

These studies at the Fraser Experimental Forest in Colorado have also provided information on the location of sap movement. By placing the heat pulse probes at varying depths in the xylem, it was found that sap moves very little in the outer 5 mm. of spruce and pine. In spruce, the peak movement occurs between 10-20 mm. deep, but does not cut off even at 35 mm. deep. In pine, movement becomes high at 10-15 mm. and remains high even at 35 mm. deep. The interesting point of this experiment is the low rate of movement in the youngest wood--wood 5-10 years old. Most of the sap appears to move in older wood.

A system to measure volume of stream discharge through the use of a dye dilution technique has been developed and proved to be successful. The system is based on the continuous injection of a solution of water and a fluorescent dye in the stream to be measured. The dye, Rhodamine B in methanol, is injected at a concentration of 1 part per 100. The ratio of rate of solution injection to rate of streamflow is on the order of 1 part dye to 2 million parts of stream water. Samples taken downstream are tested for the actual concentration and volume of flow can be calculated. For remote locations and for short-term measurements, this system has a great potential. It will reduce the cost of stream gaging from several thousands of dollars to several hundreds.

of a 4,000-acre municipal watershed on a 10-year cycle would produce, by the end of 10 years, an increased average annual water yield of 0.26 inch over the entire watershed. This is an increase of only 1.3 percent, but it amounts to 28 million gallons per year from the 4,000 acres. It is a sizeable amount, enough to supply the domestic needs of more than 1,000 people (at 70 gallons per day), or to irrigate over 170 acres with 6 inches of water. Thus, though the percent increase is small, the actual increase in volume of water is substantial. If the same volume of timber were removed by intensive selection cutting, the increase would be much less, providing not more than one-fourth of the increase resulting from clearcutting. Increases in peak flow from even-aged management in the above example would be negligible. High water quality could be maintained by following accepted safeguards in locating, constructing, and maintaining truckroads and skidroads.

Annual spraying in Arizona with 2,4,5-T following a wildfire in chaparral successfully held resprouting brush cover to less than 10 percent crown density and allowed establishment of a good grass cover. Compared to an adjacent watershed returning to brush cover, water yields increased significantly. Sediment yields increased immediately after the fire, and declined to near prefire levels within 5 years.

Soil moisture depletion was determined by measurements with the neutron probe to an 8-foot depth during several growing seasons on a series of adjacent gambel oak (Quercus gambelii Nutt.) plots at an elevation of 7,130 feet on the Davis County Experimental Watershed. Here, most of the 28 inches of annual precipitation is received during the winter months as snow. At the beginning of the growing season, the soil profile is usually fully recharged with water. In the warm, dry summer, during which only 1 to 5 inches of precipitation can be expected, some 18 inches of moisture were lost through evapotranspiration from these gambel oak plots. During the early part of the growing season, when soil moisture was abundant, plants obtained the majority of their moisture from the surface 4 feet of soil. As moisture became less available in this area, greater quantities were removed from the lower 4 feet of soil. By the end of each summer, moisture was depleted throughout the 8-foot profile. Apparently, the gambel oak and associated vegetation has a uniform distribution of feeding roots--even though the oak stems occur in well-defined clumps.

Americium-beryllium is a far better neutron source for soil-moisture meters than the older radium-beryllium neutron source. A recent evaluation made by the Forest Service in California compared these two radioactive materials and two other source materials, one containing plutonium and the other actinium. Americium-beryllium appears to be the best source now available for soil moisture meters where portability and high precision are required. The amount of time required to make a measurement can be reduced from a 2-minute count per measurement to a 1-minute count with no change in accuracy. In addition, the safety hazard of these instruments due to gamma radiation is eliminated and the weight of the instrument is significantly reduced. Already many of the neutron soil-moisture meters belonging to the Forest Service have been fitted with the newer source material.

As a demonstration of multiple-use management, a 356-acre forest watershed was established at the Coweeta Hydrologic Laboratory in the Southern Appalachian Mountains for the optimum integrated production of water, timber, wildlife, and recreation. The primary installation was a good road system built to the best specifications developed by previous research to prevent erosion and concentration of overland waterflow. The road was laid out to serve all the anticipated uses of the watershed.

An upper slope area of 192 acres was clearcut for timber production, water yield improvement, and increased forage for wildlife. A cove compartment of 92 acres was thinned to increase the quality and growth of a valuable yellow poplar stand. Sites for recreational use were improved and trout holes with low dams and deflectors were located in the stream channel. The results of these activities were remarkably successful. The road drainage system functioned well, withstanding two 15-inch storms 5 days apart without damage. Water quality was degraded only slightly; most of the turbidity came from road drainage and the scour from the trout holes. Water yield increased about 7.7 area-inches during the first 2 years of management. Volume and quality of reproduction on the clearcut area were excellent and the thinned area now supports a well-spaced, vigorous stand of yellow poplar. About one-third to one-half of all reproduction was classed as desirable deer food, and browse production totaled perhaps one-half to one ton per acre.

Despite the intensity of management, the value of the wood products removed exceeded the cost of the treatments. And the increased water yield, wildlife, and recreation benefits were all bonus values. Surprisingly few conflicts occurred; perhaps 20 percent of all management activities were conflicted and 80 percent were supplementary or complementary. Such pilot tests are extremely valuable because they clarify what is physically possible and esthetically desirable through intensive resource management. They aid in formulating resource management policy and in physical planning of management on larger land units.

2. Prevention of Watershed Damage

There are many thousands of acres of forest and related lands that are in good watershed condition. Increasing demand for use of these lands for timber harvesting, grazing, recreation, and wildlife requires that special attention be given to maintaining stable soils and controlled streamflow. Research in this area involves development of land-use practices that give special attention to the prevention of watershed damage.

a. Timber management. Differences in the hydrologic, topographic, soil erodibility, land use, and land condition potentials may be combined to estimate the sediment discharge potential for individual parts of watersheds. Between the units of watersheds in the coastal area of California, differences in sediment production associated with differences in hydrologic potential have been found to vary by a factor of 10, with topographic potential by a factor of more than 2, with soil erodibility by a factor of 8, with geologic stability by a factor of 5, and with land use and condition by a factor of 6-16. By combining the effects of all the various potentials, it has been found that the overall sediment potential for wild-land watersheds varies by a factor of 100, and for agricultural lands by a factor of 7. From these results, areas where caution in management may be needed can be determined and the effectiveness of certain types of management can be estimated.

Clearcutting for timber management and water yield improvement should not result in serious erosion and sedimentation. Clearcutting a watershed at the Fernow Experimental Forest in West Virginia, some years ago, showed that water yield could be increased; but water quality suffered in that experiment because of poor logging practices. The recent half-clearing of Fernow Watershed 6 and 7 demonstrated that a complete cutting with careful logging practices would not result in serious erosion and sedimentation. Flow has been clear most of the time and the maximum turbidity obtained, during a storm, was a modest 80 parts per million.

In the Driftless Area of the Upper Mississippi Valley, forested slopes play an important role in minimizing downstream flooding and siltation. Surface runoff from upland fields generally must pass through wooded slopes. In a 4-year study, 21 percent of all rainstorms produced runoff from ridgetop fields but only 6 percent produced runoff in the valleys below. Thus, the forests not only protect the steep slopes from runoff and erosion, but they also intercept much of the runoff from overlying fields that otherwise would contribute to downstream floods.

Simple treatments to supplement the natural effect of forest have recently been installed on the Coulee Experimental Forest in northern Wisconsin. The treatments were: logs placed along the contour in the natural forest, three detention ponds in tandem, and natural forest (control). The effectiveness of the treatments was tested by comparing outflow from the plots to inflow. First-year results show there was no outflow from the ponds, one-third from the log treatment, and two-thirds from the natural forest.

Sediments from an artificial source in Alaska caused an increase in fine material in the streambed gravels of a study riffle 600 feet downstream. This change in gravel composition is unfavorable for salmon production, but it had no effect on dissolved oxygen. Dissolved oxygen levels remained consistently high.

It appears that logging along streams may have an adverse effect on fish production. Preliminary results of water temperature studies in small north coast streams in California indicate the possible extreme effects of logging on water quality. In one stream section only 578 feet in extent, water temperature increased from 60°F. to 75°F. because of exposure to the sun. Stream sections well exposed to the sun contained dense growths of algae, while the well-shaded sections did not. Fingerling salmonids appeared to be considerably less abundant in stream sections where algae growths were extensive.

Accumulations of logging debris in Alaskan ravines can be very destructive to downstream areas during periods of high streamflow. Logging steep-sided drainageways tends to create debris accumulations in the ravine bottoms. High streamflow following heavy rains can bring this debris into suspension, creating a slurry of earth, water, and debris of great destructive power. So far, removal of debris after logging is not feasible; hand clearing is too expensive and suitable conditions for burning the debris are rare. A continuing search to reduce logging debris is necessary.

Rates and patterns of soil particle movement were determined at Wenatchee, Washington, by measuring periodic changes of radiation intensity on an eroding sandstone soil tagged with a radioactive isotope of iron (Fe^{59}). Conventional physical measurements of accumulated or suspended sediment have generally failed to identify rates of travel of soil particles, or sources of eroding soil. This study has shed some light on a means for determining when transient soil particles are to be considered erosion without collecting them for measurement at some point in their course. The use of Fe^{59} as a tracer was tested in 100-mc spot applications and 300-mc applications to a 5-foot line along a contour. The line application gave the better measure of soil erosion pattern. More than 70 percent of the isotope moved 3 or more inches from the line of application, and total movement of 6 to 8 feet was recorded during an 8-week period.

Water samples, taken before and after spraying with DDT to control Douglas-fir tussock moth in Oregon, contained no significant amount of the insecticide. Water was sampled periodically from the main drainage of a large area sprayed in 1965 at a rate of three-quarter pound per acre. However, cooperators from the Department of Fisheries and Wildlife, Oregon State University, found traces of apparent DDT or some of its isomers in various components of the aquatic food chain even before spraying was done. Post-spray samples indicate a general increase in DDT and its isomers throughout the food chain. The highest DDT residue of 1.2 parts per million was found in trout while the lowest was 0.02 ppm in herbivores. Water sampling will be continued indefinitely to assess amounts of DDT attributable to the spraying that might be present in streamwater and aquatic food chain systems.

Red alder in Oregon was found to contribute to soil fertility in much the same way as do leguminous plants. Root nodulating, and possibly phyllosphere symbionts, through their nitrogen-fixing activities, are responsible for additions to soil nitrogen. Thus, if red alder is eliminated from the ecosystem by herbicide treatments, there may be a detrimental effect on soil fertility and the soil-forming process.

Because hard-frozen ground may be impermeable or slowly permeable to melting snow and rain, it can be an important factor in the hydrologic behavior of northern watersheds during winter and spring periods. As part of a study on the effect of different tree species on soil freezing and runoff, an easy, nondestructive method of determining deep frost penetration was sought. Depth of concrete frost penetration into the soil near La Crosse, Wisconsin, was measured by four methods: modified frost penetrometer, soil moisture resistance blocks, soil temperature, Soiltest frostmeters. The penetrometer method was fast and accurate. Resistance block determinations agreed well with penetrometer measurements. Temperatures of $-1^{o}C$. indicated frozen soil, but temperature was a poorer indicator than moisture block resistance. The frostmeter is unreliable as a scientific instrument.

Multivariate statistical analysis has already shown that conventional sediment sampling is unsatisfactory for answering problems in sedimentation research and may often be unsatisfactory for answering simple needs for structural design. Analysis of existing northern California suspended sediment data suggests that, for some stations, the number of samples could be greatly reduced without impairing the accuracy of predicted sediment yield. Hopefully, the results of the analysis would engender a major shift in the method of sedimentation sampling throughout the United States. It suggests that sampling should be less concentrated on single streams but spread among many streams and tributaries.

There have been interesting changes in the chemical content of water after logging two watersheds on the H. J. Andrews Experimental Forest in Washington. Large increases in NH_4, HCO_3, and K concentrations have shown up in both watersheds. These ions probably have their source from decomposition of logging residues and roots. Maximum loss rates were found during rainstorms and then only a few days of the year. Daily losses in the logged watersheds have been about double that from the unlogged control watershed. But there appeared to be no differences in the losses between logged Watershed No. 1 and logged and burned Watershed No. 3.

Streamflow from forested watersheds in the Eastern United States that have not been logged in the past 20 years is generally of high quality, even though these watersheds probably were cut over several times during the past 150 years. Rarely do these areas show evidence of active erosion. This may be due, according to

watershed studies at the Fernow Experimental Forest in West Virginia, to a self-healing process involving development of an erosion pavement, rapid invasion of vegetation, and leaf fall. As an example of the rapidity of this process, during logging at the Fernow, 28 percent of water quality samples had turbidities greater than 1,000 p.p.m.; 3 years later 95 percent had turbidities from 0 to 10 p.p.m.; and 5 percent from 11 to 99 p.p.m. The fact that most of the erosion occurred during the logging operation strongly indicates that more attention should be paid to means of preventing erosion during the logging operation.

b. Logging road location and construction. A large proportion of sediments reaching stream channels from forested lands originates from roads. In the construction and maintenance of roads, soil disturbance is inevitable. Yet, roads are a necessary part of the process of converting overmature forests to managed stands. And, as logging pushes further into the steeper, more inaccessible forest areas, soil disturbances from road construction will increase. Procedures are being developed for minimizing erosion from road surfaces, restoring stability to fill slopes, and regaining overall absorptive capacity of disturbed soils as quickly as possible.

Although erosion may start at any point on a logged watershed, roads offer a readily available source of sediment. When in movement, this sediment has much greater scouring power than water alone. Results to date of an experiment conducted on the Payette National Forest in Idaho point up the effects of road-building. It was designed to compare the overall sediment-producing effects of two types of logging: jammer (which requires closely spaced roads) versus high-lead. Two roads were built through the jammer area in 1961. In the fall of 1962 both the jammer and the high-lead areas were logged. After 3 years of observations it became evident that logging per se (i.e., cutting and removal of trees) is directly related to increased soil movement, but its effect is negligible when compared to the effect of roads. Sediment was collected and measured behind dams constructed across ephemeral streams. Prior to road construction, no sediment was collected in either area; following road construction, more than 7,000 tons of sediment per square mile of watershed were deposited the first year. Within 3 years this rate gradually dropped to zero. However, in the fourth year the area with roads yielded 12,115 tons per square mile--compared to no measured erosion from the area without roads. As the result of a heavy storm, a pocket of soil in Deep Creek was washed downhill; the moistened soil had sufficient force to displace a road-fill, and the resulting large mass of lubricated soil developed sufficient force to excavate down to bedrock all the soil in its downhill path.

During this time, a small amount of sediment was measured from the high-lead area. It peaked in the growing season following logging at 25 tons per square mile, about 12 percent of the sedimentation from the jammer area for the same period. Thereafter, it dropped to negligible amounts.

c. Range management. Forest-associated rangelands are a primary source of waterflow. They also provide needed forage for big-game herds and large numbers of domestic livestock. Continued grazing use of these lands is dependent upon recognizing or establishing plant cover requirements for maintaining stability on these sites.

Soil erodibility studies in the southern Sierra Nevadas found that predictions of erodibility are possible from available maps of vegetation type, geology, and topography. They also found that soils at higher elevation were nearly twice as erodible as soils under similar conditions of lower elevations. Thus, extensive study of high-elevation soils will be needed, for the lower soil information cannot be applied to the high elevation conditions.

3. Rehabilitation of Damaged Watersheds

In addition to those watershed lands needing protection, there are great areas that have already been damaged by past use. Some of these damages date back many years and most of the lands remain in unsatisfactory condition. This research is designed to develop techniques and management practices to stabilize and improve soils and to restore satisfactory streamflow conditions.

a. Abandoned farmlands. In years past, many thousands of acres in the Piedmont and upper Coastal Plain of the Southeast and South and other areas in the Lake States and the Central States were cleared from forest and put under clean cultivation. Serious erosion and lowered productivity of the land have resulted in abandonment of many areas. Difficult problems now prevail to stop the active erosion and to reestablish trees and other protective vegetation on those lands.

Because it produces rapidly a mantle of soil-stabilizing litter, loblolly pine is widely planted on eroding sites in the South. In north Mississippi, the weight of this forest floor is related to the age and to the basal area of the plantation. If basal area could be held constant, the weight of the forest floor would increase about 2 tons per acre from age 8 to age 16. At a constant age, say 12 years, increase in basal area from 60 to 120 square feet due to closer spacing would increase the weight of the forest floor by about 1.3 tons. The average oven-dry forest floor weight in the plantings was 7.3 tons per acre.

Eroding streambanks along the Tobacco River in Michigan accounted for 28 percent of the total suspended sediment yield. In this area, the deep mantle of glacial drift permits rapid downcutting of the stream channels. Erosion can be controlled by the establishment of vegetation after the toe of the bank has been stabilized by rock riprap.

Bank control becomes especially important in trout habitat improvement in wild lands where other upland sources of sediment are near their minimum values. Turbidity in trout streams results in warmer stream temperatures and lower spawning potential. The sources of the finer textured sediments which cause turbidity are likely to differ with land use and soil conditions. Measurements of suspended sediments at 20 stations on the Tobacco River in north central Lower Michigan have shown that large volumes of sediment per unit area come from upland erosion on the fine-textured soils which are normally tilled. Pasture land, in close proximity to the streams, produced the highest suspended sediment yields of any land use tested.

Site index can be predicted for Ruston soils in the southern Coastal Plain over the major regions of their occurrence on the basis of April-through-September rainfall and thickness of topsoil. The prediction equation provides a basis for evaluation of these soils for forest production. It is also useful in appraisal of climatic zones and in delineating soil mapping units wherever these soils occur. This research will contribute in an important way to land use planning, appraisal, and

management of more than 2 million acres of wornout cropland. It will provide criteria for decisions by which perhaps half this acreage will be reforested, eventually providing additional income of $5 million each year as well as reducing erosion, sedimentation, and flooding.

b. Damaged rangelands. Overgrazed rangelands in Western United States are often important source areas of flood water and eroded material. Rangeland soils are often thin and sites are harsh. Past efforts to reestablish protective vegetation have frequently failed. Research in development of new and better procedures for rehabilitation is underway in several areas.

Contour trenches were constructed on the Davis County experimental watershed in Utah in 1964 to simulate those very successful installations made in the 1930's to control mud and rock flows. In the early installations no measurements were made on the effect of time on infiltration rates; studies made on the new trenches, however, showed that rates decreased markedly in 1 year to about one-sixth to one-third of the original rates. Apparently, there was a sealing of the soil surface by silt and clay. The study will continue, to determine the time-effectiveness of contour trenching.

On the Rio Puerco drainage of New Mexico, soil ripping continues to be effective in stopping runoff. This drainage is a heavy sediment contributor to the lower reservoirs of the Rio Grande. The Bureau of Land Management spends over $1 million per year to protect these eroding lands. In the third summer after ripping a 471-acre watershed, zero runoff was recorded. The control watershed of 758 acres produced 10.59 acre-feet (0.17 area-inch) of flow from summer thundershowers--a significant amount when concentrated in erodible channels in this critical problem area. Overland flow prevention provides more moisture for plant growth or for deep seepage, in addition to the reduction in soil erosion.

A prefabricated flume to measure stormflows in ephemeral streams has been developed in New Mexico. Fiberglassed plywood panels make up the sidewalls and other prefabricated components include angle iron support walls and intake box. A four-man crew can construct the flume in 10 days for $1,500.

A little known plant, Ceanothus prostratus, has many characteristics that give it a high potential for soil stabilization and revegetation on harsh sites. However, its native range is limited to the east slope of the Sierras in California, and it would be desirable to extend its range to other areas with harsh sites needing revegetation. Using a method of vegetative propagation developed recently, outplantings were made in Idaho and Utah. The results were very encouraging; survival was better in both States than at a control planting in its native range. Furthermore, in Idaho the greatest survival was found on the most severe site--a steep, unstable, infertile road fill of decomposed granite.

c. Strip-mined lands. There is a great surge of interest in the problems of strip mining among conservationists, land managers, and landowners. Forest Service research in the restoration of strip-mined lands has been increased to develop methods for minimizing damage during mining and for quickly establishing vegetation to reduce runoff and erosion and restore a pleasing and productive landscape after mining.

Revegetation of spoil banks is difficult because of the adverse chemical and physical characteristics of the spoil material. The spoils are a mixture of rock fragments ranging in size from massive chunks to sand, silt, and clay-sized particles. The soil fraction is classified either as a loam or clay loam, which generally favors plant growth. Spoil samples from six eastern Kentucky coal seams were found to range from medium to extremely acid, with generally low concentrations of total soluble salts and organic matter. Exchangeable calcium was low in all whereas magnesium was abundant. This imbalance may adversely influence plant growth. Available potassium and phosphorus were present in low to adequate amounts for plant growth. Available iron, manganese, aluminum, and sulphur were present in amounts believed to be toxic to many plants. This information on spoil characteristics pinpoints revegetation problems and will aid in the selection of plant species, soil amendments, and spoil placement techniques to facilitate mine spoil revegetation.

Contour strip mining often leaves a wide, unstable bench. A recent survey in Kentucky indicated that about 12 percent of the outslope area from benches was in slides. Seventeen slides were measured and plotted for a slope stability analysis using the method of slices. Density, Atterberg Limits, soil classification, and shearing characteristics were found to be similar for all slides. Designed stable fill bench widths ranged from 36 feet on a 58-percent slope to 100 feet on a 27-percent slope, assuming also that the site was prepared (vegetation scalped) and proper drainage control exercised. Minimizing slides will result in more stable bank conditions and permit rapid restoration of a permanent vegetative cover for watershed protection.

The multiple watershed method of conducting watershed experiments offers several advantages over the traditional methods in which a predisturbance calibration is required. A relatively new approach, it is useful where ownership patterns (such as surface mine or road construction areas) preclude a closely controlled and long-term experiment. In this method, a large number of non-uniform watersheds are selected. The parameter to be evaluated, (streamflow, sediment, etc.) becomes the dependent variable which is statistically related to a number of independent variables such as watershed area, area of disturbance, in addition to climatic factors. Advantages include: (1) the results are applicable over broader regions, (2) there is more flexibility in selecting experimental areas, (3) downstream effects of the disturbance can be determined, and (4) the method is applicable on a sampling basis.

d. Burned watersheds. Fire-induced floods and erosion from steep, unstable watersheds are a serious problem in some parts of the country--particularly in southern California. Records show that flood peaks can increase 68 times and erosion rates can increase 28 times following fire. Floods and erosion at greatly accelerated rates not only impair watershed productivity but also are a threat to downstream population centers. Methods for quickly stabilizing destructively burned watersheds are under development.

Grass and barley cover established after the serious wildfire on the San Dimas Experimental Forest east of Los Angeles, California, may not have been completely beneficial in all cases. Although it reduced debris movement and may have reduced the hydrophobic characteristics of some chaparral soils, it also held back the recovery of native vegetation. In some cases this effect may have been beneficial, for the grass and barley roots are better distributed in the surface soils; but on some sites, prone to mass soil slippage, the native species with their deeper

rooting habits are preferable. Thus, research has been able to devise better recommendations to take care of the exceptional cases. The planted barley proved to be the most successful emergency treatment for the first 2 years following the fire. A 65-percent reduction in debris yield was attributed to this treatment during the second year. But then the barley stand deteriorated rapidly.

The hydrophobic, or nonwettability, characteristics of some soils make them resistant to infiltration of rainfall and cause overland flow of water and subsequently debris. While nonwettability can be detected on both burned and unburned brushland areas, it is probably more important on freshly burned watersheds. Laboratory experiments indicate that the heat of a brush fire intensifies the water repellent characteristics of soils which are already somewhat hydrophobic. Following a fire the hydrophobic layer is usually found at about 1 to 2 inches below the soil's surface and may be 2 to 4 inches thick. The surface soil above the strongly hydrophobic layer has been rendered completely wettable by the higher temperatures of the fire. Chemical wetting agents, tested in plot-sized studies, have counteracted the nonwettability, increased infiltration, and have reduced erosion by 95 percent. The most recent research has determined that the wetting agent would probably be effective for at least 1 year.

4. Soil Improvement

There are more than 25 million acres of wetland forests ranging from the bogs of the northern Lake States to the swamps of the southeast Coastal Plains. Most of these lands are headwaters for countless streams, and are recharge areas for ground-water supplies in certain localities, but they support only low-growing heaths or degenerate forests. Although their inherent wetness makes management difficult, wetlands have potential for greater forest production if soil-water relations can be improved. Development of management alternatives which will upgrade productivity yet conserve regional water supplies is dependent upon the improved hydrology of these soils. It is an area where there is a dearth of information.

Since 1947, water levels have been altered on about 2 million acres of wetland forests in the South, and this activity is continuing at an undiminished rate. Woodland water management is used to improve community water supplies, produce forage from otherwise nonproductive wetlands, maintain wetland vegetation in natural areas, impound water for waterfowl use, bring open pineland into production, and improve the soil productivity of marginal wetlands. Many wetland forest landowners consider all drainage to wet sites desirable, but this is not always correct. It is necessary to discriminate between sites where water control is beneficial and those where it may be harmful or of little benefit. For example, bottomlands and swamps are highly productive for hardwood timber and wildlife. Here, water management is generally aimed at maintenance of natural water levels, including some application of water when necessary. On the other hand, 3.5 to 4 million acres of wet flats can be improved for pine production by woodland drainage, as may other areas of coastal plain bays with mineral soils. But bays with deep peat soils are not much improved by drainage. Thus, it is necessary to identify the problem and understand the processes involved before undertaking wholesale application of water control measures.

In Minnesota, the forest cover in bogs perched above the regional ground-water table is of a lower quality than in bogs being replenished by ground-water flow. The perched bog, simply a closed impervious basin, receives its water entirely

from precipitation. As rainwater has practically no nutrient content, the bog is a poor forest site and has a restricted variety of plant cover. The water flowing through the ground-water bog, on the other hand, has picked up chemical nutrients from mineral aquifers. This is reflected in a richer community of plants and a better forest site.

The perched bog has greater annual water surface fluctuations than the latter bog. This may well result in greater storage capacity for spring snowmelt and rainstorms than that of the true ground-water bog.

5. Public Law 480 Projects

a. Monographic revision of the genus Tamarix. Saltcedar, one of the most troublesome phreatophytes of the Southwestern United States, belongs to the plant genus Tamarix, which is native to the Middle East. Phreatophytes generally consume large amounts of water; therefore, considerable study is being made of methods for controlling saltcedar and replacing it with a plant cover having lower water requirements. To better understand the growth requirements, environments, and parasites of the several species, as an aid to control, the genus Tamarix was studied in depth at the Department of Botany, Hebrew University, Jerusalem, Israel. A definitive final report has been completed: Baum, B. 1966. Monographic revision of the genus Tamarix. Final Research Report. Department of Botany, Hebrew University, Jerusalem.

The work included an examination of living plants collected throughout Israel and Turkey, and material from many herbaria in Europe, Asia, Africa, and the United States. Of interest to phreatophyte researchers in the Southwest, is the finding that there appears to be two major species in the Western United States, T. ramosissima and T. chinensis. Heretofore, they were both included in T. pentandra. Both species are Asiatic in origin, rather than Mediterranean as previously assumed. In their native habitat they are associated with soils of differing salinity. The concept of two separate species will be studied further in this country, using plants that have naturalized and spread widely throughout the West, even as far north as Montana.

b. Study of difference in effects of forest and other vegetative covers on water yield. The increasing need for water in the United States and other parts of the world has focused attention on the effects of different vegetative types on total water supplies. In low rainfall areas the most economical use of land may involve planting those vegetative covers requiring the smallest amount of moisture. The Israel Soil Erosion Research Station has recently begun a project to study the moisture availability from four different land-use areas--bare land, lands covered with grass, oak-chaparral, and pine forests.

During the first 6 months, the most interesting results were those obtained with the transpiration tent. The tent was erected on two contrasting study plots: pasture and maqui (oak-chaparral). Four series of comparisons were taken during May through October. Preliminary results show that the maqui used about 6½ times as much water as did the pasture. During the period, transpiration by the pasture decreased from 0.5 mm. per day to 0.2 mm. per day. Maqui transpiration was consistently six or seven times this amount in all four runs.

c. Seasonal variability of soil moisture and levels of groundwater table on lowland areas, as they affect water use, growth and development of pine stands. Coniferous trees do not grow well in wetland areas where flooding and high water tables prevail during parts of every year. Little is known about the conditions required for successful production of conifers in these areas. To supplement the two wetlands projects in this country, a 5-year grant has been issued to the Forest Research Institute in Warsaw, Poland. Field work will be done in three regions of Poland where stands of pine are established on sandy soils. Important environmental factors to be measured include precipitation, interception, soil and air temperatures, ground-water levels, and soil moisture by gravimetric and lysimetric methods. Water balance computation will be made to determine the role of forest stands, especially their water consumption under several site and meteorological conditions. Response to different environmental conditions will be determined by circumference and height measurements of trees and stands.

Laboratory studies to strengthen and interpret field research will be carried out in the greenhouse under controlled conditions of temperature, humidity, and precipitation.

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B. FOREST RECREATION RESEARCH

Problem

Who uses the forest for his outdoor recreation enjoyment? Why does he come there? What does he do? How long does he stay? What are his impacts upon the forest resource? We know that each year he brings more of his fellow Americans with him--last year the National Forests alone received 150 million visits. But what is really happening? Will their interests and tastes be the same 10 years from now? What adjustments must be made in the management of the forest to meet the needs yet retain the resource? It is the goal of forest recreation research to help answer these questions. More specifically, its task is to obtain facts and test alternatives to (1) guide the planning, management, and enhancement of America's forest beauty for millions of recreation visitors; (2) develop criteria for profitable income-producing recreation enterprises on privately owned forests and woodlands; (3) find effective low-cost methods for restoring and maintaining heavily used forest recreation sites to provide criteria and methods to select, develop and maintain at low cost new forest recreation sites which will be heavily used; (4) develop ways to obtain more dispersed and less destructive use of areas especially sensitive to deterioration; (5) provide guides to obtain efficient coordination of recreation with other resource uses of the forest; and (6) provide a better factual basis for policy and management of wilderness and multipurpose forest lands through ecological, economic, and user studies that lead to enhancing and effectively maintaining esthetic forest landscapes and attractive recreation sites and surroundings.

USDA and Cooperative Programs

Research at 8 of the 10 Forest Experiment Stations is underway toward answering these problems. Studies fall into three broad categories--those dealing with forest recreation use, those directed at the forest recreation environment, and those dealing with the economic aspects of forest recreation. Each Station is concentrating its studies on selected critical problems, often national or interregional in scope, rather than attempting a program of research embracing the broad spectrum of problems found in its geographical region. Most of the studies are in cooperation with other Federal, State, and educational institutions. Staffing varies according to the research emphasis, and currently scientists from seven different disciplines make up the professional staff.

A total of 21 professional man-years of effort was devoted to forest recreation research during the past year (intramural--research by Forest Service scientists).

Progress--USDA and Cooperative Programs

1. Effect of recreation on forest environment

Recreation user preferences must be blended with resource capabilities. A New York State study shows that campers who use car-access campgrounds in the Adirondacks have a predominate preference to camp as close as possible to a lake. However, when tent sites are placed within 15 to 20 feet of a lake's shoreline, erosion and dessication of shoreline environment caused by camper activity frequently causes the esthetic quality of the scenic resource to be lost. If unique intangible values of water-resource environments are to be preserved for future recreational use, public managers must blend user preferences with resource capabilities.

In the Adirondack spruce-fir forest type, a 100 to 200-foot-wide strip of intervening shoreline vegetation on a 3-4 percent gradient permanently screens tent sites from the lake, allows the lake to be viewed from most tent sites, and increases the lake's multiple-recreation potential.

The strong demand by recreationists for water-oriented recreation and the resultant effect of this demand on the shoreline vegetation suggests that recreation user fees for this resource be proportional to the environment's uniqueness and to the cost of preserving and maintaining its original esthetic quality.

Wilderness--How can it be heavily used? How can its esthetic values be maintained? Wilderness means many things to many people. For the wilderness manager and administrator it means "How can the public have its cake and eat it too?" This problem is in particularly sharp focus at Minnesota's Boundary Waters Canoe Area. The BWCA sustained 250,000 visits in 1965 and more are expected this year. Soils throughout the area are thin and fragile, and even lightly used campsites have lost 50 to 99 percent of their ground cover, and tree reproduction on these sites is absent. Erosion compaction and root exposure are prevalent.

Visitor preferences were strong for campsites in pine stands and on islands. Interviews clearly showed that most of the canoeists do not realize they are damaging the sites for camping. Most apparently believe that campsite maintenance means picking up trash, and the only campsite problem is that of debris left by previous campers. Educational programs in wilderness camping are urgently needed. These should include the fundamentals of forest ecology and encourage dispersed use. In addition to Forest Service visitor information programs, there is a fine opportunity for assistance through the cooperation of equipment outfitters.

A recent survey found that 62 percent of the canoeists relied heavily on canoe outfitter pamphlets in planning their canoe trips, and an estimated two-thirds followed routes suggested by the outfitters. An organized routing plan could be developed by the Forest Service and Canadian officials in cooperation with the outfitters. This should help bring about a better distribution of use. This year, for the first time, BWCA visitors must register, and as their numbers continue to burgeon use may have to be limited and designated. Such limitation of the freedom of choice and movement may be the price the wilderness recreationist must pay to insure preservation of the basic wilderness resource and of the kinds of canoe campsites he prefers.

Watch for hazardous trees at heavily used recreation sites. Each year as more visitors come to the forests the odds for injuries from decayed and mechanically weak trees increase. Lodgepole pine, one of the important species in both intensively used and extensively used western recreation areas, was studied from a hazard standpoint in California. Many of the lodgepole stands are old-growth--a circumstance that adds to the enjoyment of the species but results in a larger portion of defective trees. Five Sierra Nevada sites were examined. One-third of all the trees had butt rot, one-half of these were rated potentially hazardous. Furthermore, potential hazard increased with amount of recreation use at the site, three to four times greater on high-use sites. Thirty-nine percent of all the trees over 10" d.b.h. were rated potentially hazardous at the most heavily used site. Fire scars were the most common abnormality associated with decay and hazard. Ground squirrel holes were frequently found at the base of decayed trees. Although the presence of a ground squirrel hole suggests a high degree of decay in the associated tree, the absence of squirrel holes does not imply a sound tree.

The study underscores the need for careful inspection of lodgepole pine in recreation areas where the trees are fire scarred, often overmature, and exempt from commercial cutting.

Coordination of fertilization, irrigation, and use can help maintain heavily used recreation sites. Can fertilization and irrigation strengthen vegetation at heavily used sites? A Utah study provided the not surprising results that fertilization increased the vigor of vegetation, especially if nutrients that were previously lacking are supplied. Broadcasting of fertilizer aided ground cover more than trees. Trees were helped when fertilizer was placed in holes drilled in the soil at the root zone. Timing of watering is very important. Watering just before heavy use may soften soils and make vegetation turgid and increase the possibility of damage. Watering after heavy use, however, can aid survival by keeping bruised vegetation moist until it has a chance to heal.

In this regard, the study turned up an item much less obvious. Although trees compete with ground cover for moisture and nutrients, they also control the amount of direct sunlight reaching the forest floor. Bruised plants have little chance of recovering if they dry out before healing. Hence, arranging recreation layouts to take advantage of shade may substantially enhance the survival of heavily trampled ground cover.

A related study of use shows that vegetation survival was greater when use was frequent but fairly light, rather than infrequent but heavy. For instance, just one good volleyball game may be more damaging than several weeks of lighter use.

2. Forest recreation use

Four concepts to consider in the application of forest landscape management. There is great concern as to how to preserve and enhance the "natural beauty" of the forest environment. The natural and industrial landscape of forest and range lands was analyzed in a cooperative study with the University of California. The problems of landscape management can be identified in terms of the following four concepts.

(a) Nature may be thought of as a continuum between scenes dominated by man's land-use changes and scenes relatively protected from encroachment. There is a need to preserve natural areas for scientific and educational purposes regardless of, or even in spite of, their visual composition. However, this need should be separated, conceptually at least, from the beliefs held by many people that the highest forms of beauty are found in nature.

(b) Beauty is an especially relative matter, but its complexity should not deter a start toward comprehensive consideration of beauty in landscape use. Awards are given for creative architecture and thoughtful design on the urban scene: homes, office buildings, and bridges, for example. Why not search for and recognize creativity and good taste in nonurban land use? There is need for a positive critique of practices in farming, grazing, logging, and watershed management, and of such developments as forest roads, visitor facilities, mines, and power stations and their place within the environment.

(c) Meaning depends on both the viewer's predisposition and the way in which the environment is presented to him. To increase understanding of how parts of the environment relate to each other and to the whole, one can either educate observers to relate these conceptually, or one can manipulate the environment to make interrelationships clearly visible. The conservation approach has traditionally placed heavy emphasis on training exemplified by interpretative programs or education in natural science.

The importance of the educational approach is obvious, for there are limits beyond which the inner character of the land cannot be outwardly revealed. But there is also a need to increase the emphasis on landscape design, thus opening an avenue to creative intuition, as well as intellect. For example, the ordinary landscape could be managed to bring out land's content and function, with the drama of nature and land use expressed through design.

(d) Imageability connotes attributes of a scene that give it a high probability of evoking a strong image. Certain visual patterns and objects act as foci, landmarks, clues, or symbols, helping people form vivid images and impressions. For example, observers tend to notice things which already have strong or symbolic meaning for them. Many will be shocked by the sight of bulldozers, slash piles, and tree stumps; but they may be reassured if these manifestations are seen as part of a full cycle of harvest and growth and if it is obvious that the land is being used with care. It is incumbent on the resource manager to identify those aspects of his work that are visually striking and meaningful to observers.

Each of these landscape characteristics could become a distant focal point for establishing public policy, providing paths for research, and through design, provide the means to enhance and explain the landscape of resource use.

Knowledge of visitor use patterns can help in planning visitor information programs. A study of Michigan campers provides some guides for the manager in setting up visitor information programs. Variety in information programs from day to day, but not between weeks, would appear to be adequate. This is suggested by the low frequency of trips per family and the average length of trip--5 days. Turnover of families was high and most stayed less than a week.

The predominance of families with children raises the problem--how to present information to hold the interest of both children and adults, especially when three-fourths of the children are of preschool and elementary school age. The opportunity to inform the adults is not fully met by pitching all programs at a child's level of understanding. A solution might be to aim daytime presentations at children and night presentations at adults. The study further showed that these families have the capacity and interest to understand fairly sophisticated presentations of information, but similar to BWCA visitors, their knowledge of land resource management was limited and they were confused by the reasoning behind land management objectives and policy decisions.

Accurate measures of dispersed and concentrated recreation use of forest lands will assist efficient resource allocation and management.

(a) The heads of 1,532 households were interviewed at 18 exit points for information concerning use made of the 100-square-mile study area on the George Washington National Forest in Virginia. Developed-site camping, hunting, sightseeing, and fishing were the most important forms of recreation in the study area. Deer hunting provided by far the most hours of use.

The most important user attributes relating to participation in component activities were zone (or distance from the area), age, education, occupation, and income of the head of household. In addition, the average period of participation per visit varied considerably among groupings within certain socioeconomic attributes which were the same as user attributes.

Results from this study show that a stratified random sampling plan (with no prior knowledge of how to optimize sampling effort) can produce good estimates of total and component recreational uses. In addition, we detected significant, important relations between users and uses as a basis for providing decisions for present and future recreational management--criteria for selecting management alternatives.

(b) The Davidson River Recreation Area Complex on the Pisgah National Forest in North Carolina consists of 8 developed recreation sites--two picnicking and three camping sites ranging from 8 to 42 family units; one observation site; and two sites with both picnicking and swimming facilities. Pneumatic traffic counters were placed on all site entrances to tally total vehicle crossings. In addition, single traffic counters were placed across the main highway at each end of the recreation complex.

Close approximations of number of visitors and amount and kind of use were obtained for each of the eight individual sites, based on traffic count records obtained at each respective site. Total season-long visit and use estimates for all eight sites combined, based on traffic count records from one or more selected locations, were even more precise than were estimates for individual sites. For example, one of the counters placed across the main highway consistently produced acceptable use estimates. If all conditions remain fairly constant, this is the only counter that need be installed and maintained during the next few years to produce recreation-use estimates on all eight developed recreation sites.

Within the next decade or less, Forest Service expenditures for development and management of National Forest recreation resources will aggregate several hundred million dollars of public funds. Use information must be accumulated and utilized accurately and inexpensively to provide a basis for sound planning and budgets. Mass and dispersed types of recreation use on Florida's Ocala National Forest were estimated during a one-year period by simultaneously using (1) double-sampling and (2) stratified random sampling techniques. The Forest received almost 1,500,000 visitors, and 29 million hours of total use, during the sampling period.

The two sampling techniques, used simultaneously, worked very well and their results were highly comparable. It appears that only slight modifications need be made in the stratified random sampling system to accommodate almost any combination of area size and road network pattern.

Fishing excellence overemphasized in Boundary Waters Canoe Area. A study of fishing as an attraction and activity in the Quetico-Superior Area in northern Minnesota shows that fishing has an important impact upon use despite the fact the region's beautiful streams and lakes are not good fish producers. Advertisements heavily emphasize spectacular fishing and often produce unrealistic expectations and disappointment. Fishing seems to be of minor interest, however, to paddle canoeists. The activity is of much more importance to motorboat campers, day users, and resort guests. Dissemination of more accurate fishing information might lessen use and use impacts by these nonpaddle visitors.

3. Economics of forest recreation

Who are the customers for privately owned campgrounds? A midwestern study of people using private campgrounds along the Ohio Valley was made to learn what kind of people go camping, what things such people seek, and why they select certain campgrounds. Camping is an outdoor recreation activity of growing importance which readily lends itself to development on small, private woodlands. Profitable campground operation, however, depends much upon how well the entrepreneur anticipates the facilities and services wanted by campers; upon how well he estimates his potential market; and upon how well he understands the kinds of campers he hopes to serve. Little of such knowledge is presently available for the potential private campground developer.

Private forest campground users generally camp as a family; only a few groups studied were not members of a family. For many of the family groups, this was their first year of camping. The majority of the camping families came from urban areas. The head of the camping family earned a higher-than-average annual income for his area of residence. Families camping out for just a weekend usually camped with another family, participated in several other outdoor activities, had traveled less than 100 miles to the campground and used either a travel trailer or tent trailer.

Families camping while on a major vacation, on the other hand, tended to camp alone, participated in very few other outdoor activities, had often traveled more than 100 miles to the campground, and used a tent more often than any other type of shelter. Such campers, additionally, were more interested in conveniences such as showers and laundry facilities than were the weekend campers.

The small woodland owner planning to develop a campground can benefit much from the study results. The results provide valuable information about the type of facilities different kinds of campers will be looking for. If the woodland owner planned to cater to transient campers, for example, he should place more emphasis on personal convenience facilities than upon other outdoor recreation facilities. If he planned to cater to weekend campers, however, he should emphasize the development of such things as swimming areas, hiking trails, boating areas or outdoor sport areas. The would-be campground operator must decide which type of camper he can best serve and then develop his enterprise according to what such campers will be looking for.

Knowledge of recreationists' preferences can guide acquisition and development. The President's Outdoor Recreation Resources Review Commission has stressed the need for studying the preference patterns of individuals and groups in order to learn the directions and amount of total recreation demand. By using such information managers can begin to anticipate patterns of demand and can be prepared to meet them.

Results of a photo-choice survey of recreationists at four northeastern Pennsylvania State Parks showed that on both weekdays and weekends campers differed significantly from noncampers in their preference patterns for swimming areas, fireplace design, camping facilities, and campsite spacings. Furthermore, study results suggest that recreationists who use State parks on the megalopolitan fringe prefer and are willing to pay for modern recreational facilities set in an open, spacious environment surrounded by a tapestry of woodland.

Implications for land-acquisition programs are that open farmlands that have scattered woodlots and lakes, or streams that can be dammed for artificial lakes, probably are more desirable for public and private recreation development for this segment of the public than large tracts of heavily wooded areas.

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C. RANGE MANAGEMENT

Problem

Forage production on extensive areas of rangeland is far below potential and fails to meet the needs for livestock and game grazing. In many areas, particularly in the western mountains, watershed values have been seriously impaired by severe grazing. Management of these lands is often complicated by variable and droughty climate, highly erodible soils, and sensitive vegetation that cannot withstand close grazing use. Furthermore, livestock grazing must be coordinated with wildlife use and often with timber production. Improved management practices must be developed to allow sustained forage production in harmony with other uses and values.

Special phases of the range management problem are: (1) to determine growth characteristics and requirements of range vegetation, (2) to evaluate forage, classify range condition and trend, and develop better vegetation measurement techniques and range inventory procedures, (3) to develop optimum management systems to obtain maximum production and efficient use of forage on the various types of rangeland, (4) to determine effects of fire on vegetation and soils and to develop practical guides for its use in controlling undesirable plants and in increasing quantity and quality of forage production, and (5) to ascertain the ecological relations of rodents and other range pests as a basis for their control.

USDA and Cooperative Programs

This is a continuing, long-term program of both basic and applied research at numerous locations in the various range plant communities of the West, Midwest, and South in cooperation with State colleges, universities, and agricultural experiment stations; with the Smithsonian Institution, Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, Agricultural Research Service, numerous herbaria, private companies, and livestock associations or individual ranchers. In addition there are two PL-480 projects: germination of seeds of desert plants (Israel) and studies of botany, ecology, and biology of the principal species in mountain pastures of semiarid regions (Spain).

The Forest Service scientific effort involved in this research totals approximately 45 professional man-years.

Progress - USDA and Cooperative Programs

1. Characteristics and Requirements of Range Plants

a. Ecology and physiology. Studies on plant growth in relation to the various environmental factors provide the necessary information for the development of effective grazing management practices. Most of these studies are problem-oriented, but others merely aim to uncover fundamental facts about operation of the many range ecosystems. Although usefulness of some information from this type of research is not readily apparent, it serves to broaden the base for eventual attack on practical problems.

On high elevation ranges in Utah, tall bluebell (Mertensia leonardi) starts growth immediately after snowmelt, grows as much as 1.4 inches per day, and dries up and becomes useless as forage by mid-summer. During the period of most active growth in late June, even moderate defoliation (40 percent) for 3 consecutive years reduced production 75 to 85 percent. Heavy defoliation (70 percent) in late June reduced production 90 percent, and complete removal of all herbage reduced production almost 95 percent. Similar defoliation treatments in early June, before the most rapid growth period, or in early July, after the plants were mature but had not yet become dry, were much less damaging than the late June treatments. This study will provide basic information needed to properly manage ranges containing tall bluebell. It appears that use on such ranges should be rotated so that any given area is not grazed during the period of most active growth of bluebell for 2 successive years.

Other studies in Utah indicate that plants vary greatly in their reaction to herbage removal. Clipping mountain grassland vegetation harmed the forbs much more than the grasses. Production of Aster integrifolius and Potentilla gracilis was adversely affected by a single clipping to a height of 4 cm. just before and during flowering. After 3 years of clipping, herbage production and number of flower stalks of these species were reduced approximately 50 and 80 percent, respectively. Festuca idahoensis, Bromus marginatus, and Agropyron trachycaulum generally were most harmed by clipping from flowering to seed ripening. Three years of clipping at the most sensitive stage reduced herbage production of these three species 0, 35, and 45 percent, respectively, and flower stalk numbers 95, 35, and 50 percent, respectively. The grasses generally benefited, at least temporarily, from reduced forb competition, and clipping caused a conspicuous shift in herbage composition toward the grasses. Total herbage production did not decrease significantly until the third year.

On Colorado mountain grassland range, grasses appear to be better competitors than forbs in the absence of grazing. Three years after removing all forbs (with selective herbicides) grasses comprised 95 percent of the total cover. Where grasses were removed (with selective herbicides) the plant cover had become 64, 23, and 13 percent perennial forbs, annual forbs and perennial grasses, respectively. Plots on which the entire resident plant cover was killed were reoccupied the next growing season by a profusion of annual forbs even though this group of plants was only a minor component of the pretreatment cover. Combined application of nitrogen (350 lb/acre) and phosphorus (300 lb P_2O_5/acre) significantly increased the foliage cover of Thurber fescue (Festuca thurberi) and virtually excluded the increase or reestablishment of perennial forbs. Cover of Fremont geranium (Geranium fremontii) as well as that of other less abundant forbs was not increased by the soil amendments. Moreover, nitrogen-phosphorus applied to the denuded plots had an inhibitory first-year effect on the invasion of annual forbs; by the second year these plants were becoming established on the denuded plots even though applications of the amendments were made annually.

Greenhouse tests of three alpine soils in Wyoming indicated that the natural fertility of glacial till soils was greater than soils derived from either volcanic breccia or ash. The breccia soils ranked second and the ash soils were the least fertile. Soil amendments--nitrogen, phosphorus, and potassium--improved the productivity of all three soils. Phosphorus was the most limiting nutrient in the glacial till soil. However, potassium and nitrogen fertilization resulted in some increases in shoot production. Nitrogen was the most limiting on the breccia and ash soils, but nitrogen additions suppressed phosphorus responses. Maximum yields were obtained on these two soils when both nitrogen and phosphorus were

added to the soil. Under field conditions, the ash soils produced little vegetation. However, in the greenhouse where soil moisture was maintained constantly within the range of availability to plants, production increased even with the exclusion of the three soil amendments. This indicated for this soil that field application of the soil amendments would provide questionable benefits unless the moisture regime were improved.

A form of vegetative reproduction has been described for Carex ebenea, an important forage producing alpine sedge. When normal sexual flowering occurred, several leafy, semi-prostrate stems developed. In the axils of the leaves along these stems, small bulbils formed from which additional leaves developed and grew rapidly. The leaves were thicker, darker green, and more lustrous than those of the parent plant. The bulbils were easily detached from the parent plant and if placed in water, immediately sprouted roots. Some of those rooted in water were placed in soil and developed new plants. Both the root and shoot development were more rapid from these small bulbs than the growth from seedlings.

Cool, white influorescent light, plus an incandescent source, was slightly superior for the growth of sedges (Carex sp.) in the greenhouse as compared to the Gro-Lux Wide Spectrum light. In addition, some sedges required very low light intensities to initiate growth, flower, and produce seed. This partially explains the growth of some sedges that takes place under snow on alpine ranges.

Seed germination of Parry's clover (Trifolium parryi) was 86 percent after seed immersion in 75 percent sulfuric acid for periods of 20-30 minutes. This treatment may provide a practical means of inducing germination when propagating this valuable alpine forage species. Concentrations of 35 percent acid failed to improve germination, but the 55 percent concentrations increased germination from 19 to 38 percent.

Stocking capacities on mountain grasslands in Utah are not fully developed until after forage growth is completed. In a study of the influence of weather on yearly variations in plant development and yield, started in 1964, forage development and total production varied greatly among years. This complicates management for efficient utilization. As yet, it is not possible to predict accurately either the appropriate starting date or the total production of forage associated with yearly variations. Fixed stocking rates based on average forage production will result in overgrazing in some years and underutilization in others. Data collected for 2 years at an elevation of 7,100 feet show that increased precipitation markedly increases production, and low spring temperatures slow down the rate of plant growth. High precipitation during the growing season in 1965 (47 percent above that obtained in 1964) increased herbage production on north slopes approximately 90 percent and on south slopes approximately 15 percent. These preliminary data suggest that precipitation is more effective on north slopes than on south slopes, and consequently, greater variation in forage production can be expected on the former. With additional information, it is hoped that the influence of weather variations on vegetation can be sufficiently well understood to determine in advance range readiness and yearly stocking capacities.

The lodgepole pine type occupies 14.5 million acres in the West--9 million acres in the Intermountain area and 4.7 million acres in Montana. Clearcutting of lodgepole pine encourages abundant herbage production, which provides important forage for livestock and game while a new timber stand develops. Although livestock and game now graze some clearcut areas, a much greater potential appears to exist than

is currently being utilized. The purpose of this study is to determine forage composition and production on lodgepole clearcuts as related to environment and post-logging practices, and to determine the persistence and sequential changes in the post-logging vegetation.

Samples from 22 clearcuts on 6 soil series in Montana indicate that herbage production is related to soil series. The amount and variety of forbs appear to be the most sensitive indicator of soil productivity; grasses are the poorest indicator and shrubs are intermediate in this respect. A striking difference in vegetal composition is evident on one soil series where shrubs comprise 1 percent of the cover, as contrasted with 25 to 37 percent on the other series. Bitterbrush (Purchia tridentata) is the only shrub species on this series, and it does not occur on any of the others studied. This particular soil is a coarse loam over "obsidian" sand and gravel, with a moisture retention capacity that is apparently too low for most shrubs.

In Oregon a seasonal pattern of carbohydrate accumulation-depletion was found to exist in both tops and roots of bitterbrush, a nutritious shrub browsed by both livestock and big game. Mobilizable carbohydrate accumulations declined during the early growing season and reached an extended period of low percentage and low weight during the rapid twig growth and seed formation stages between mid-June and mid-August. Following this, buildup of reserves set in and continued until leaf fall, thus restoring carbohydrate accumulations to a high point a little above their prevernal level. The study results provide guides for management of bitterbrush range for livestock and big game in Western United States.

With a good mixture of grasses, a pinyon-juniper range in northern Arizona should supply ample green forage from April 1 to September 30, and some green feed all winter. Cool-season grasses reached peak height between May 18 and June 23, and remained partly green all year. Warm-season grasses were green only during spring, summer, and fall, and reached peak heights between September 11 and September 21. These facts were learned from 4 years of observation of plant phenology and growth in the pinyon-juniper type in Arizona.

The amount of growth of each species was highly variable, and was determined mostly by precipitation a month or two just prior or during the period of most active growth of each species. The dates when certain growth periods occur were orderly and fairly predictable. Cool-season grasses grow at a nearly uniform rate from April 10 to May 10. Grazing systems should provide for occasional rest for both cool- and warm-season grasses during their growth periods. Warm-season growers can be favored by resting during the July 15 to October 15 period and cool-season growers by resting during April, May, and June. Because of differences in time of peak development of important grasses, forage production measurements should be taken in June for cool-season species and in September for warm-season species.

Annual and perennial grasses and burroweed (Haplopappus tenuisectus) compete strongly for moisture on semidesert grass-shrub range in southern Arizona. Where annual and perennial grasses occur on the same area, perennial grass yields were reduced about 20 percent and annual grass yields by about 50 percent. Both kinds of grasses depend greatly on moisture in the surface 12 inches of soil during the summer but the perennials have an apparent advantage over the annuals in the use of this moisture since the annuals must start from seed each year, whereas, the perennials are already established. Where burroweed and perennial grasses occurred together, perennial grass yields were reduced about 20 percent. In addition, the growth of burroweed measured by crown cover was only about half as great in the presence of perennial grasses as when growing alone. However, burroweed competes less severely with perennial grasses because it used soil moisture in the early spring when the grasses were essentially dormant, and in the late summer or early fall after the grasses had completed most of their growth.

There was minor competition for moisture between burroweed and annual grass because major growth of each occurred at different periods of the year.

Measurements showed that most available soil moisture accumulated during the winter was expended to a depth of 2 feet or more before the summer rains began, even on bare plots. Most of this depletion was due to evaporation as well as to use by burroweed which begins to use water rapidly in late January or early February. The common native perennial grasses did not start using soil moisture until some time in March. The annuals used moisture mainly during the summer. This study has demonstrated that on shrubby ranges of the semidesert grassland type, from 30 to 100 percent of available soil moisture may not be put to beneficial use under present practices. Research is now attempting to determine how to make beneficial use of this moisture.

Ranchers in the southwestern Ozarks of Missouri claim native bluestem ranges grazed continuously through mid-summer cannot be maintained. The problem, therefore, is to determine when foliage removal is least detrimental and develop a grazing management system to promote maximum sustained yield of this range.

Periodic clipping to simulate grazing effects on yield and initial tillering of plants of Andropogon scoparius, A. gerardi, and Sorghastrum nutans show maximum forage yields cannot be sustained by grazing every year in mid-summer. But, yields can be increased by grazing after plants mature. Clipping after floral initiation, but before anthesis, was most damaging to plants. These results, therefore, suggest fall and winter grazing; however, grazing these grasses in fall and winter precludes their use when they are most palatable and nutritious. Therefore, a grazing management system of rotating summer rest periods with summer, fall, and winter grazing use is suggested for maintaining these grasses in this grassland. Further research is needed for developing a practicable and economically sound rest-rotation system of grazing for Ozark forest and glade ranges.

b. Taxonomy. A continuing effort is required in plant taxonomy to provide reliable identification of the complex floras of the many range plant communities. During the past year 3,900 plant specimens were identified for Forest Service research and administrative personnel, and members of other Government agencies. Approximately 3,000 specimens were mounted as permanent vouchers for the Forest Service Herbarium. This "working" herbarium now contains approximately 140,000 identified and annotated specimens from all parts of the United States.

On the basis of these annotated specimens, a comprehensive publication on western range forbs (broadleafed herbaceous plants) was released. This well-illustrated volume provides descriptions, characteristics, distribution, and forage value of 470 important range forbs, and will be an invaluable tool in range and wildlife habitat research and management efforts.

2. Range Vegetation Evaluation

a. Forage value. Since livestock welfare and performance are closely related to palatability and nutritive value of the forage, efforts are being made to determine quality of various kinds of forage plants by chemical analysis, in vivo and in vitro digestion studies, and by practical grazing management trials.

Bluestem ranges occurring in the Ozark region are thought to be deficient in nutrients during most of the season. However, a study of seasonal variations in grazing behavior showed 500-pound growing heifers could acquire enough protein to satisfy the minimum requirement throughout the season by consuming adequate forage supplied by forbs and browse. This study also showed the heifers could not satisfy the minimum requirements for phosphorus from grasses, forbs, and browse after May, regardless of plant selection. This strongly emphasizes the need for a phosphorus supplement to Ozark range forage early in the grazing season.

The amount of protein from the rumen contents of fistulated steers on the Santa Rita Experimental Range in Arizona varied from 1.53 to 1.91 times greater than that of hand-clipped samples of major perennial grasses, Arizona cottontop (Trichachne californica) and Lehman lovegrass (Eragrostis lehmanniana). Steers enhance the protein of their diet by selecting the succulent parts of the grasses and by using shrubs and annual forbs with high protein values when available. Although the protein content in samples from the rumen was highly correlated with that of the grasses, the relation was too variable to have much predictive value. Therefore, a reliable estimate of the nutritive value of a steer's diet can be obtained only from samples that the steer selects. Steers fitted with rumen fistulas can provide the necessary "steer-selected" forage samples.

In Wyoming, addition from the saliva of esophageal fistulated wether sheep accounted for an increase of 72.66 percent and 22.33 percent in the moisture content of grass hay and green grass, respectively, in the fistulas as compared to noningested material. This added moisture was directly related to the dry matter content of the ingested sample. Added ash was 2.94 percent and 3.43 percent of grass hay and fresh grass, respectively, through an esophageal fistula. Added nitrogen was 0.45 percent and 0.19 percent for esophageal collections of grass hay and fresh grass. Those results were obtained from a study to learn the nutritive and digestive qualities of range forage, knowledge becoming increasingly important when evaluating range management practices.

A constant-temperature water bath was developed for use in artificial-rumen (in vitro) digestion studies. The bath costs less than $65 as compared to $1,260 for commercial equipment of the same capacity. The bath accommodates over 250 digestion tubes of 100 ml. capacity.

b. Vegetation measurement and sampling. Over the years, progress in range research and management has been impeded by difficulties in obtaining quantitative measurements of vegetation, particularly herbage production. Consequently, range scientists are continually searching for better methods of vegetation measurement and sampling.

In Wyoming, four vegetational characteristics--foliage cover, stem numbers, stem length, and leaf length--were consistently correlated with and used to estimate herbage production. Use of these correlated characteristics to estimate production on a single occasion was less efficient than direct measurement. Where periodic change in production is of primary concern, the advantages of permanent sample units may outweigh the inefficiencies of double sampling.

Data from a modification of the angle-order distance measurement method were compared with plant counts and weight estimates on plots and with cover estimates from line intercepts on sagebrush-grass range on the Snake River plains of Idaho.

The angle-order method was effective for measuring density (number), production, and ground cover of species that occur as distinct individuals such as arrowleaf balsamroot (Balsamorhiza sagittata) and threetip sagebrush (Artemisia tripartita), but not suitable for sampling species in which individual plants are difficult to distinguish. Because of these limitations, the angle-order method is not suitable for sampling entire communities but it may be an efficient method to determine density, production, and ground cover data for one or two key species.

c. Condition and trend. Good range management requires fundamental information about the range ecosystems, particularly sound methods for determining condition in relation to potential and for recognizing and evaluating changes resulting from grazing use. It especially requires sensitive indicators of trend to allow early applications of corrective measures.

Studies in southwestern North Dakota show that total forage production decreased on all sites under grazing, the grazed areas producing only 50 to 80 percent as much as the ungrazed. The forage yield on ungrazed sites averaged 787 pounds dry-weight per acre, and on grazed sites only 474 pounds per acre. Mulch, including both fresh and humus mulch, was also much reduced. Ungrazed areas produced an average of 3,940 pounds per acre while grazed areas produced only 2,157 pounds. Rate of water infiltration on all range sites was dramatically reduced by grazing. Infiltration rates for the second inch of applied water averaged 6.0 inches per hour on ungrazed range and 3.1 inches per hour on grazed areas.

In other North Dakota studies, climatic fluctuations resulted in considerable yearly variations in range condition ratings, one whole condition class in some cases. The variations are due largely to the greater response of the mid-grass species to differences in yearly growing conditions compared to the small yearly fluctuations of responses of short grass and forb species. The data imply a need for caution in applying the quantitative-ecologic approach to range condition classification. More than 1-year estimates are needed to give reliable estimates. Moderate grazing as occurring on ranges in good condition caused a drastic reduction in yield of the mid-grass components, but basal cover data showed very little change in basal cover of mid-grasses. Obviously, much of the reduction in yield of the mid-grass species was the result of reduced vigor rather than reduction in percentage of basal cover. Therefore, in order to restore these ranges to higher production capacities, it is necessary to set up those conditions which promote the restoration of vigor, not conditions needed to restore the species in the cover. A rest-rotation system of grazing would give plants the needed rest to restore vigor and also increase species number if necessary.

Grass production on weedy rangelands in western Colorado increased almost as much under improved management as on areas that were not grazed for 19 years. After many years of close grazing, grasses produced 162 pounds per acre or only 18 percent of the total herbage in 1941-42. With lighter grazing, grasses comprised 39 percent of the vegetation and produced 300 pounds per acre versus 353 pounds per acre on the ungrazed range in 1960. Essentially there was no difference in the relative composition of grasses, forbs, and shrubs between the grazed and ungrazed ranges. Conspicuous changes in the grass herbage components occurred during the 19-year period, particularly on ungrazed range. Slender wheatgrass (Agropyron trachycaulum), bromegrasses (Bromus spp.), and trisetum (Trisetum spp.) accounted for 63 percent of the grass herbage in 1960 as compared to 14 percent in 1942. In contrast Letterman needlegrass (Stipa lettermani), sedges (Carex spp.), and bluegrasses (Poa spp.) contributed 65 percent at the beginning but only 27 percent at the conclusion. Similar but smaller changes

occurred under restricted grazing.

A method of stepwise regression analysis using seasonal precipitation amounts was found successful for predicting forage yields of seasonal crested wheatgrass (Agropyron desertorum) ranges. Precipitation accounted for 88 to 97 percent of the variations in yields at the Manitou Experimental Forest in central Colorado. April precipitation provided the best predictor of forage yields on ranges grazed only in the spring. For ranges grazed only in the fall, May-July rainfall was most useful for predicting yields. For ranges grazed both spring and fall, April-May precipitation provided the best prediction of spring yields and June-July rainfall for fall forage production.

Size and numbers of crested wheatgrass plants were more affected by severe drought during one growing season than by 8 years of seasonal grazing treatment at Manitou Experimental Forest. In 1963, rainfall, which was only 51 percent of average during the first 4 months of the growing season, resulted in partial or complete death of many plants regardless of grazing treatment. Prior to 1963, plants on fall-grazed ranges were tending to aggregate. By 1964, their basal intercept was reduced and they had fragmented into smaller units. Plants on the spring only or the spring-fall grazed ranges, which were smaller prior to the drought, were completely killed. By 1964, basal intercept of crested wheatgrass on all ranges was similar regardless of grazing treatments.

Effects of grazing on forest soil were studied in central Louisiana. Although grazing did not alter bulk densities and porosity alarmingly, percolation and infiltration were slowed sufficiently to materially increase runoff during intense rainstorms. This could accelerate erosion and limit soil water available for plant growth. Hence, forest soils that are highly erodible or inherently very slow in water intake should be grazed only lightly and for brief periods, if at all. On most longleaf pine sites, moderate grazing should prove reasonably compatible with forestry objectives, as grass rough left by the cattle impedes runoff and reduces the erosion hazard. Heavy grazing for long periods is hazardous to all forest sites. These determinations of grazing effects on range soil afford essential guides to land use management and grazing use on over 2 million acres of flatwoods range in Louisiana and Texas. The study, costing less than $10,000, establishes safe limits of grazing intensity for a range resource that can net as much as $6 million annually.

3. Livestock Grazing Practices

a. Native ranges. Although studies of ecology, physiology, taxonomy, forage value, and vegetation measurement are basic to the development of range management practices, actual grazing trials are necessary to determine the true worth of such practices. Also, it should be recognized that results of such trials cannot be widely extrapolated; consequently, separate grazing studies must be conducted for a wide range of native plant communities and environmental conditions.

Investigations at Saylor Creek Experimental Range in southern Idaho are directed toward a long-range goal of developing improved methods of management for millions of acres of cheatgrass range on the Snake River Plains and Columbia Plateau. To date, basic data have been collected on both vegetal and animal responses to seasonal grazing treatments. Brief periods (2 weeks) of heavy grazing by cattle have revealed the apparent seasons when important species are most susceptible to grazing damage, although effects on vegetation have not been great.

Treatments of longer duration evidently are required to substantially modify the vegetal composition. Yearling cattle can gain an average of 1.5 pounds per head daily for an April-to-November grazing season, and sheep can gain about one-third pound daily for a 6-week season in April and early May. Marked yearly and seasonal differences in animal gains occur, and seem to be related to quantity and quality of feed available and to effects of weather. Data from these studies are being utilized to design new procedures and systems of grazing which, it is believed, will permit more efficient utilization and management of cheatgrass ranges.

Studies on the Starkey Experimental Range in Oregon have shown that proper range management practices of fencing, development of watering facilities, salting program, range riding and herding, and improving livestock access to forage areas can accomplish uniform livestock distribution and forage utilization. These practices are directly applicable to more than 7 million acres of forested and related grazing lands on National Forests of the Pacific Northwest. Sustained forage production and use by 95,000 cattle and 93,000 sheep on National Forest allotments is dependent upon these improved range management practices. This information also has general application to all western rangelands.

Forage production on a northern Arizona forested range increased as the crown cover of ponderosa pine decreased. Slash removal by piling and burning provided higher forage yields 2 years after thinning than where slash was left on the ground. Arizona fescue contributed a high proportion of the cattle diet early but this proportion decreased through the grazing season. The contribution of mountain muhly to the cattle diet was just the opposite--low early in the grazing season and higher later. A direct relationship was found between digestible forage consumed and yearling cattle weight gains. These are preliminary results of research designed to discover the effects of ponderosa pine density on forage and beef production.

Winter weights of cattle at Tonto Springs in the Arizona chaparral were maintained better on native chaparral range than on ranges where the brush had been root-plowed and the areas seeded to weeping lovegrass (Eragrostis curvula) and Lehmann lovegrass (E. lehmanniana). Yearling steers and heifers lost only 0.07 pound per day from November through April on the native range as compared to an 0.4 pound per day loss on the improved winter range. Longtongue muttongrass (Poa longiligula) and squirreltail (Sitanion hystrix) provided the bulk of the grass forage from the native pastures. Weeping lovegrass provided the most forage from the improved range. These are preliminary results of research designed to evaluate the relative values from native chaparral range and ranges converted to grass in Arizona.

Preliminary results from a 10-year study that is nearing completion show that reducing grazing use from 56 percent to 40 percent of the forage and changing from yearlong grazing to alternate-year summer deferment increased possible income from beef production by more than $1 per acre per year. Similar income increases could be obtained by applying these practices to 6 million acres of relatively high potential semidesert range in Arizona alone.

In Montana, steepness of slope of a grazing area was found to considerably influence distribution of cattle. On a 10 percent slope, where access is only from the bottom, 75 percent of the use is likely to be within 810 yards of the foot of the slope. On a 60 percent slope, 75 percent of the use is likely to be within 35 yards of the foot of the slope. Distribution is also influenced by distance from water. A formula was developed whereby relative use can be predicted from

percent slope and distance upslope. This formula can be used to adjust grazing capacities on several million acres of mountainous grasslands in the northern Rocky Mountains.

b. Improved ranges. In addition to various types of native range, optimum seasons, intensities, and systems of grazing must be developed for ranges improved by burning, seeding, fertilizing, plant control, or other cultural practices. Effective management practices are especially needed for seeded areas throughout the West and for areas where low-value trees and shrubs have been converted to grassland.

Many poor-site Ozark hardwood stands produce little usable wood, livestock forage, or wildlife food. Spraying with chemicals to eliminate low-quality hardwoods can result in improved livestock range and wildlife habitat. A stand of post oak, blackjack oak, and hickory in west-central Arkansas was aerially sprayed once in 1957 with 2,4,5-T. Grasses preferred by cattle increased temporarily. Reinvasion of woody plants and heavy grazing by cattle contributed to a subsequent decline in yields of grass. The invading shrubs included many species preferred by deer. If the purpose of spraying is to improve cattle forage, then respraying at less than 8-year intervals is suggested. Continuous overgrazing should not be allowed. If deer habitat is the main consideration, spraying should be less frequent and in alternate strips or small blocks.

To be fully productive, forest range in the Southeast must be supplemented with concentrates and/or improved pasture. Consequently, a study was designed to evaluate various programs for providing improved pasture in a spring-summer grazing program in southern Georgia flatwoods. Cattle performances under spring-summer grazing treatments involving unsupplemented forest range, improved pasture, and combinations of the two were compared over a 6-year period. Where controlled winter burning is compatible with good timber management and other land management practices, burned range is a cheap source of much valuable feed in a cow-calf livestock operation. Annual calf production was 325 pounds per cow on native range (with high level of fall-winter feeding) and 376 pounds per cow on improved pasture. At 25 cents per pound for feeder calves the return from range was $80 per cow and from improved pasture $94 per cow. The results enable landowners to select a productive spring-summer grazing program which can be adjusted to their ranch situation.

On the Manitou Experimental Range in Colorado, average calf weaning weights for 3 years were 32 pounds greater from a herd using a series of seeded and native ranges than from a similar herd that grazed only native forage. Difference in weaning weights between the two systems resulted primarily from a higher level of nutrition for the herd grazing Sherman big bluegrass (Poa ampla) during the fall. The protein content of this species in the fall as determined from rumen samples, averaged 3.8 percent higher than the native species. Average for the 3-years data is as follows:

Herd	Calf weights (pounds)	Selling Price
Seeded-native range	424	$106.81
Native range	392	$ 99.11

The average return per calf was $7.70 greater for those animals that grazed the seeded-native range combination. Gains and market values were greatest from these ranges when the native forage cured early in the fall.

These results are applicable to 4 million acres of similar ranges in the Front Range of the Rocky Mountains.

On the Benmore Experimental Range in Utah, feeding the daily equivalent of 3/4 of a pound protein supplement to cows and yearlings on crested wheatgrass was more beneficial in dry years when there was no summer or fall regrowth of grass, than in wet years when forage remained green. Animals receiving supplements on crested wheatgrass gained about the same as unsupplemented animals on mountainous summer range. Cows benefited significantly from the supplement, but their calves were affected very little. Yearlings did not benefit from the supplement, possibly because cows tended to push them away from the feed.

On other areas of crested wheatgrass range at Benmore, late fall sheep grazing reduced big sagebrush 52 percent beeween 1962 and 1965. During the same period, big sagebrush increased 56 percent under early spring cattle grazing. Sagebrush yields remained constant where fall sheep grazing was combined with early spring cattle grazing. Under these conditions (less than four brush plants per 100 square feet) sheep usually maintained their weight during the fall period. They lost weight and did not reduce brush yields where brush was dense (10 plants per 100 square feet). Apparently fall sheep grazing is an effective measure for sagebrush control if treatment is started before the brush becomes too dense. There are some 2 million acres seeded to crested wheatgrass in the sagebrush type. Since spraying with herbicides costs from $3.50 to $5 per acre, brush control by sheep grazing offers a way to save considerable money while gaining an extended period of livestock use.

The poisonous introduced annual weed, Halogeton glomeratus, which was found near Wells, Nevada, in 1934, has spread over millions of acres of western rangelands. Invasion of halogeton into seeded crested wheatgrass ranges in central Utah was associated with intensity of grazing, season of grazing, spring and summer precipitation, soil disturbance and concentration of soil salts. Heavy infestations were found on areas which were heavily grazed in spring and early summer. Maintenance of desirable vegetation by proper grazing evidently prevents invasion of this poisonous plant.

Research has indicated that deferring grazing after sagebrush control on some Wyoming rangelands does not provide added benefits. These results apply to the dense sagebrush range at higher elevations that receive good moisture and have a good understory of good forage plants. If deferment is practiced there would be a direct cost of $4 on the original $6 return per dollar invested for the control operation for herd reduction or acquisition of additional forage. Assuming this analysis is applicable to most National Forest land in Wyoming where sagebrush control is feasible, the annual savings to the livestock industry would be approximately $40,000. The results also have application to adjacent Government and private land being treated. Further studies are needed to verify these results and test them under other conditions.

Grazing capacity is increased as a result of applying sulfur or sulfur-plus-nitrogen fertilizer on annual-plant range at the San Joaquin Experimental Range. This benefit from fertilizing occurs both in the winter and spring "green forage season" and the summer and fall "dry forage season." The first 3 years of a study showed that 60 pounds of sulfur will increase grazing capacity by as much as 45 percent on "dry season" range and 82 percent on "green season" range. Sixty pounds of sulfur plus 80 pounds of nitrogen will increase grazing capacity by

as much as 141 percent on "dry season" range and 145 percent on "green season" range. When the cost of rangeland, equipment, and labor was less than $5.86 per acre per year, the cost of grazing was less where sulfur was used than where sulfur-plus-nitrogen was used to fertilize the range. This was because sulfur-plus-nitrogen was four times more expensive than sulfur alone. These results are applicable to 1-1/2 million acres of Sierra Nevada foothill range.

4. Burning and Other Range Improvement Practices

Ranges are often so deteriorated by overgrazing or other disturbance factors that good grazing management alone cannot be expected to restore them within a reasonable period of time. Consequently, it is often necessary to manipulate the present vegetation by such practices as burning, spraying with herbicides, or applying mechanical measures. Also, seeding desirable forage species is often necessary.

Laboratory studies in Idaho have shown that critical tissues (growing points) of needle-and-thread (Stipa comata) and squirreltail (Sitanion hystrix) can endure a given temperature from applied heat much longer in late summer after plants have matured, than in spring and early summer. Needle-and-thread can endure 130° F. up to about 200 minutes and squirreltail about 125 minutes in September; but only about 20 minutes at this temperature is fatal to tissues of both species in May. The time required to kill the tissues drops rapidly for temperatures above 130°F. for any season studied. These results are proving useful in evaluating cause of damage from fire and in planning prescribed fires.

A hot fire on the Santa Rita Experimental Range in southern Arizona in June 1963 killed 8 and 25 percent of the velvet mesquite (Prosopis juliflora var. velutina) in stands of black grama (Bouteloua eriopoda) and Lehmann lovegrass (Eragrostis lehmanniana), respectively. The higher kill on the lovegrass area was attributed to the hotter fire resulting from the greater amount of available fuel. The fuel supply was estimated at 4,480 pounds per acre in the lovegrass area as compared to 2,200 pounds per acre in the black grama area. Sprouting after the fire was then twice as great on the black grama area as compared to the lovegrass area (39 percent vs. 17 percent). Fire killed 90 percent of black grama plants and more than 98 percent of the lovegrass. However, dense Lehmann lovegrass stands were quickly reestablished from seed on both the black grama and the lovegrass areas by late September in the year of the burn. These new plants developed seed the first growing season after the burn.

Studies in Florida have demonstrated that proper use of fire is essential to improved management of multiresources in the pine-wiregrass type. Periodic burning maintains wiregrass productivity, improves forage quality, and controls cover of competing shrubs. Recommendations on frequency of fire, season of burning, and pine-forage relations will enable landowners to increase forage production without damage to pines. This has also contributed to a better understanding of fire ecology in the plant community.

Studies of rootplowing to control shrub live oak in the chaparral of central Arizona have shown that the blade should be at a depth of 1 foot. Plowing with the blade in excess of 2 feet deep, or missing areas between strips results in reestablishment of the shrub and lowered production of the seeded grasses.

Range fertilization has been proven economically sound on many ranches in California's annual-plant area. Additional acreage might be fertilized if better methods of application were available. Ground application is impractical on much of the steep, rocky foothill range. Fertilizing this kind of range with fixed-wing aircraft may also be impractical. In studies at the San Joaquin Experimental Range, a helicopter has been used to make two applications of soil sulfur on 457 acres of steep, rocky foothill rangeland. These two applications of 60 pounds per acre, 3 years apart, were successful; rate and distribution of fertilizer was good, and cost was reasonable. The average cost was $2.85 per acre for each application. The average cost of the soil sulfur was $1.62 per acre per 3-year period. Thus, the use of a helicopter appears to be a practical and economical method of application of fertilizer to much foothill rangeland.

Crested wheatgrass (Agropyron cristatum) stands in northern New Mexico reached an equilibrium with the environment within 5 to 8 years, regardless of rate of seeding or drill row spacing. Herbage yields were essentially the same for 2-, 4-, and 6-pound per acre seeding rates and for 6-, 12-, and 18-inch row spacings in the fifth, sixth, and eighth years after seeding. The results indicated that seeding rates less than the usual 6-pound per acre rate could be used to reduce seed costs. Since the 2-pound rate produced slowly developing stands except with unusually favorable weather conditions, the 4-pound rate would save nearly $1 per acre in seeding costs.

5. Range Pest Influences and Control

Troublesome range pests such as rodents, rabbits, insects, and disease are known to cause forage losses of considerable magnitude, but the actual effects on grazing values and soil and watershed are not well understood. Neither are the circumstances responsible for a buildup of damaging populations nor the conditions necessary for their control. This research is aimed at determining the identity and ecological relations of these pests as a basis for their control.

Poisoning pocket gophers (Thomomys talpoides) on native subalpine ranges in northern Utah reduced the population by one-half after the first year of control. Three additional years of control failed to reduce the gopher population further. Perennial herbage production on the area where gophers were controlled for 4 consecutive years was two to three times greater than on the area where gophers were not controlled. Perennial forbs, especially bulbed plants, were favored more than the grasses on the areas where gophers were controlled. The cost of the initial year of gopher control was $1.13 per acre and the average cost per year for retreatment was $0.51 per acre. On such sheep range, where the development and maintenance of a high producing stand of forbs is desirable, several successive years of poisoning pocket gophers would seem justified to improve the range and increase ground cover to stabilize the soil. If one-half of the extra forage (600 pounds per acre) were utilized, the carrying capacity would be increased approximately 0.5 AUM per acre per year. Assuming a commercial rental value of $3 per AUM, this increased capacity is worth slightly more than the initial control cost, and substantially more than the subsequent yearly cost of retreatment.

During the winters of 1962 -63 and 1963-64, small mammals extensively damaged the buds and bark of the stems of red elderberry (Sambucus racemosa), an important fall browse species on aspen and other subalpine ranges in Utah. The long-term effect of this damage to density or production of elderberry is not yet known. Feeding trials, population densities, and stem damage data indicated that long-tailed voles (Microtus longicaudus) and not deer mice (Peromyscus maniculatus)

were responsible for most of the damage. When enclosed with live elderberry plants, long-tailed voles fed extensively on bark and buds, but deer mice did not. Summer population of long-tailed voles decreased considerably from 1964 to 1965, while the population of deer mice remained nearly the same. Because of the decreased vole population, stem damage to elderberry was very light during the winter of 1964-65.

In September, deer mice were more numerous on crested wheatgrass ranges in Utah that had been grazed lightly (50 percent) by cattle in the spring than on units grazed moderately (65 percent) or heavily (80 percent). Mice readily occupied temporary paper shelters (2 x 4 feet) that were placed on the ground to mark plots. Mice preferred shelters that were open to the east over those open to the south, north, or west, probably because of greater protection against prevailing wind. From one to five mice were found under individual shelters, two mice being most frequent. Mice apparently established territorial areas, because the closest shelters occupied were 105 yards apart, although there was opportunity for closer association. Food caches contained mainly mature heads of crested wheatgrass, small bulbs of Poa bulbosa and heads of snakeweed (Gutierrezia sarothrae). Moth wings were found commonly, but grasshopper legs and wings only occasionally. These observations suggest that mice populations tend to build up most on ranges where most herbage and litter remain following grazing.

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D. WILDLIFE HABITAT MANAGEMENT

Problem

Wildlife habitat, by supplying food, cover, and water, is the key to optimum game and fish production. Management of habitat is complex. Each species of animal has rather specific habitat requirements that must be balanced with production of water, timber, and forage for livestock. Demands for all uses of forest and related range lands are increasing, and serious situations have arisen, often with severe impacts on game and fish habitats. Consequently, wildlife habitat research is needed to develop effective and harmonious management practices for the various vegetation types.

Specific phases of the problem are: (1) to devise methods for restoration of deteriorated habitats or for improvement of those naturally unproductive; (2) to develop and evaluate management systems through studies of the nature and degree of competition between wildlife and livestock, effects of timber production and cutting practices on forage for wildlife, and reciprocal effects of forage production and grazing use on timber reproduction; and (3) to determine the effects of land use on fish habitat and to develop ways to improve fish habitat and food supplies by such means as regulating shade and water temperatures, manipulating riparian vegetation, and stabilization of streambanks.

USDA and Cooperative Programs

This is a continuing, long-term program of both applied and basic research at numerous locations in the various plant-animal communities throughout the United States. It involves interrelations of wildlife and livestock, and integration of timber and forage values to allow optimum production and utilization of each. Studies are conducted in cooperation with various State and Federal agencies such as fish and game departments, agricultural experiment stations, Fish and Wildlife Service, Soil Conservation Service, Agricultural Research Service, Bureau of Land Management, and in some instances with sportsmen associations, private companies, and individuals. In addition, there is a PL-480 project concerned with quantity, quality, and seasonal variation of food resources available to red deer (Poland).

The Forest Service scientific effort involved in this research totals approximately 30 man-years.

Progress--USDA and Cooperative Programs

1. Wildlife Habitat Improvement

Improvement of wildlife habitat requires the development and evaluation of such special practices for increasing food and cover as seeding, planting, burning, spraying, and fertilizing. Satisfactory methods of revegetation are particularly needed to restore seriously depleted big-game winter ranges of the West. Improvement measures are also needed for naturally unproductive habitats and for the establishment of desirable streamside vegetation for the production of fish.

Closed stands of juniper-pinyon in Utah produce from practically 0 to 150 pounds (green weight) of forage per acre. Restoration of such ranges by juniper-pinyon eradication and seeding of desirable grass, forb, and browse species has resulted in greatly increased forage production for deer and livestock. On a 4,000-acre tract there was a sevenfold increase in forage production 3 years after treatment. Forage increased from about 100 pounds per acre to an average of nearly 700 pounds per acre. Deer-day use per acre averaged 4 deer days on untreated juniper stands and 83 deer days of use per acre on seeded areas 3 years after treatment--about a twentyfold increase. Deer were attracted to the seeded areas from adjacent untreated range. This is heavy deer use, but such use apparently has not damaged the forage plants. Average deer use of seeded range over the State may be less than reported here, but greatly increased grazing capacity appears possible on many critical deer winter ranges. Forage on seeded areas was available earlier and was more palatable than that on untreated range. The adequate supply of green forage on seeded areas during the critical early spring period, when fetuses are developing rapidly in pregnant does, is of special value. The improved forage reduces winter and early spring mortality and increases fawn production. Also, livestock grazing capacity on restored areas was increased greatly. Untreated range with dense stands of juniper-pinyon is practically worthless as cattle range. About 4 acres of seeded range will support one cow per month without undue interference with deer use. A fee of about $2 per AUM (based on competitive bid) is now being charged for cattle spring grazing on some restored ranges owned by the Utah State Department of Fish and Game. The improved range furnishes high-quality forage.

Watershed values are greatly improved when juniper-pinyon range is restored. Closed stands of juniper-pinyon have large, bare soil openings, and cover is inadequate to protect the soil. Ground cover averages 25 percent on untreated areas of dense juniper, as compared to 73 percent on improved and seeded areas. Such cover has stabilized the soil.

Based on recommendations developed by cooperative research of the Intermountain Station and the Utah State Department of Fish and Game, about 50,000 acres on 30 areas of winter game range in Utah have been restored successfully. Recommendations have been formulated for the future restoration of about 75,000 acres in Utah and adjacent States. Such recommendations with modifications are believed to be applicable to over 13 million acres of game and game-livestock range in Utah and large areas in adjacent States.

Striking variations have been found in populations of several native and seeded shrubs which indicate favorable possibilities for improving shrubs by both selection and breeding. Individual plants of big sagebrush growing side by side exhibit extremes of palatability to deer: one being closely cropped and the other ungrazed. Similar differences are found in little rabbitbrush, juniper, and other browse species. Palatable and unpalatable strains of rubber rabbitbrush have been isolated, and the more palatable strains are being used in game range restoration. Several other shrubs show great promise for improvement by selection and hybridization. Fourwing saltbush hybridizes in nature with shadscale saltbush and Gardner saltbush. Fertile seed is readily obtained by controlled crossing, and in preliminary work intergeneric crosses of fourwing saltbush with spiny and spineless hopsage (Grayia) have been successful. The native mountain-mahoganies and other interspecific crosses are frequent in nature and intergeneric crosses in the bitterbrush-cliffrose-apache plume group have been found. These great variations and the compatibility for interspecific and intergeneric hybridization indicate exciting and profitable possibilities for development of tailor-made shrubs with qualities to fit the various habitats and uses.

Knowledge of the factors responsible for high mortality of bitterbrush plants in the seedling year in southern Idaho is essential to overcome the losses, or to finding ecotypes resistant to the causal agents. Results of studies to date do not permit conclusions on causal factors of mortality, but they do help to characterize temperature-exposure relations and indicate the influence of temperature and soil moisture on seedling growth. Experimental sites on five exposures provide a comparison of contrasting temperatures. High soil surface temperatures (130°-140°F.), potentially damaging to bitterbrush seedlings, occurred on southwest slopes by early June in each of the 2 years of study. These high temperatures did not occur on east, southwest, or west slopes until mid-June, nor on northeast slopes until July. Temperatures above 150°F. on the soil surface occurred during the mid-July to mid-August period on southeast, southwest, and westerly slopes. The amount of herbage produced by bitterbrush plants was least on the southwest slope and greatest on southeast slopes; intermediate yields were obtained on northeast and westerly slopes.

Development of seral vegetation following forest fires in the early 1900's produced large areas of important big-game habitat in northern Idaho and western Montana. Continuing development of vegetation, however, is destroying this habitat as conifers overtop some shrubs and other shrubs grow out of reach. Some replacement ranges are being created by logging, but the general trend has not been reversed. Maintenance of valuable big-game resources of the northern Rockies will be largely dependent on our ability to manage forest vegetation to integrate wildlife values with other resource uses.

Under certain circumstances, these big-game browse ranges can be materially improved by aerial spraying with 2,4-D and 2,4,5-T. Studies of shrub response to these herbicides show that plants too tall for game use can be killed back to cause resprouting of vigorous new growth within the height zone available to deer and elk.

Shrub adaptability studies in the Black Hills indicate that Siberian pea tree (Caragana arborescens) may be compatible with ponderosa pine (Pinus ponderosa) and thus provide valuable feed for deer, grouse, and turkey in areas where the pine suppresses most other palatable shrubs. Preliminary findings also show that this shrub is very resistant to browsing by deer and, in fact, is enhanced by it. Unprotected plants of this species have generally outgrown and outproduced protected plants under open ponderosa pine stands. However, Siberian pea tree planted on an old burn site has not developed vigorously and suffered severely from grasshopper damage.

Many areas in the Ozarks produce only minimal amounts of wildlife food. Studies in other regions indicate that prescribed burning can improve the quantity and quality of wildlife food. A single controlled burn on a noncommercial timber site in summer or early fall increased production of forbs and legumes preferred by deer and turkeys. Palatability of some desirable wildlife plants was increased for at least 1 year following burning. Spring burning was not as effective and late fall burns were not recommended because of exposure of bare soil through the winter.

Effects of heat and moisture on leguminous seeds were studied in the Southeast to explore possible mechanisms by which fire may benefit several species of leguminous plants through its direct effect on the seeds. Moist and dry heat treatments were applied to seeds of Cassia nictitans for varying times and intensities. Results indicated that moist heat was more effective in increasing both rate and total germination. Laboratory experiments simulating field conditions were conducted

where moist and dry fuel beds containing seeds were burned. Results provided possible insights in explaining year-to-year variations in the occurrence of herbaceous leguminous flora in flatwoods pine stands burned annually.

Vegetative propagation may be a practical means of securing planting stock for improving forage and cover conditions in southern forests. Under greenhouse conditions in east Texas, stem cutting from American beautyberry, flowering dogwood, black willow, and common greenbrier rooted consistently enough to warrent recommendation for vegetative propagation. Rooting of 11 other species was poor or erratic. Two species did not root at all. Propagation of the easy rooters by cuttings is useful in supplying plants in proper stages of growth at specified times and as a means of maintaining genetic purity of a particularly valuable parent plant.

2. Integration of Wildlife, Livestock, and Timber Production

Successful integration of wildlife and timber production in the various forest types requires information on effects of timber stand structures on forage and mast production and on reciprocal effects of wildlife on timber production. In order to harmonize use by livestock and wildlife (particularly big game), it is necessary to know the nature and degree of competition for forage at different seasons of the year and how management practices can be modified to allow most efficient utilization of the entire resource.

Even-aged management in the Southeast promises to benefit both forestry and wildlife habitat by providing such an abundance of regeneration following clearcutting that the deer herd is well fed, yet enough seedlings and sprouts escape to insure a well-stocked productive forest. Much of the regeneration noted to date has been seedlings and sprouts of below-ground origin. Deer have much to do with influencing composition because they prefer the more succulent sprouts, allowing valuable seedlings to escape. Deer perform a valuable role in holding sprouts in check, therefore small clearcuttings are advantageous. Deer and other game are attracted to clearcuttings where they are more easily harvested.

Three years after a heavy commercial cut in Southern Appalachian cove hardwoods, seedlings were almost four times as numerous as sprouts, yet received only one-fourth the use by deer (3,520 seedlings received 14 percent use, and 995 sprouts received 57 percent use). Preference seems more closely related to growth rate or succulence than to plant species. It was apparent that much more forage was produced than utilized.

Effects of an intensive cleaning on browse production were studied in the Southern Appalachians. All woody stems except selected crop trees were removed from a dense, 11-year-old hardwood sapling stand which developed after a clearcut. Significantly more browse occurred in treated than in untreated stands. Treated lower slopes contained 10 times more browse than upper ones (805 to 81 pounds per acre), but untreated stands had only 3 pounds per acre on both slope positions. A high-quality, mixed hardwood stand resulted, and a significant increase in browse production occurred.

Northern hardwood poletimber stands are usually low in value for wildlife. A new method of intermediate cutting in these stands yielded deer browse as well as better timber. All stems except the future crop trees on selected, 10-acre blocks were felled in winter to yield an abundance of new browse in the tops of felled trees,

and in the preferred stump sprouts that come up in the spring. An attempt was made in felling the trees to hinge the stem to the stump to keep the tops alive for future browse production and for small-game cover. In the first year after cutting, the yield was 141,000 twigs of deer browse per acre--more than a tenfold increase in production over that in unthinned stands. The location of the cuttings is determined after wildlife needs have been integrated in the overall planning for each management unit.

Caspar Creek is a small coastal stream which serves as a spawning ground for steelhead and silver salmon. It is the site for an intensive cooperative watershed study of the effects of logging and roadbuilding by California Division of Forestry, California Department of Fish and Game, California Department of Water Resources, Humboldt State College, and Pacific Southwest Station.

Results obtained in 1965 indicate that: (1) Stream sections exposed to the sun supported dense growths of algae, while well shaded sections did not. Fingerling salmoids appeared to be considerably less abundant in the areas of dense algae growth. (2) Water temperature measurements showed that water depth and degree of exposure to sunlight markedly affected the stream. In one instance, stream temperature varied 15° over a distance of only 578 feet. This suggests logging may have an extreme effect on stream temperatures, both from decreasing the amount of shade and from spreading and leveling of the streambed by logging activities. (3) Terrestrial insects, as well as aquatic insects, may contribute considerably to the food supply of fishes in Caspar Creek.

Turkey mullein (Eremocarpus setigerus) is an important plant for game-bird food. This plant, a late maturing summer annual, grows on soil moisture left over after other plants have completed their growth cycle. In 1965 a study was started at the San Joaquin Experimental Range to determine the effect of mowing annual-plant range in the growing season to simulate grazing at several intensities. There was an obvious relationship between frequency of mowing and amount of turkey mullein. Only occasional turkey mullein plants grew on plots mowed once at the end of the growing season. Twenty-four times as many plants grew on plots mowed every 2 weeks. There were 13 times as many turkey mullein plants on plots mowed every 3 weeks and 6 times as many on plots mowed every 4 weeks. This is good evidence to explain why game managers can expect more turkey mullein on fully grazed or mowed annual-plant range.

Forage is a harvestable product in the 58.5 million acres of loblolly-shortleaf pine-hardwood forests of the South but yields are largely governed by timber overstory. In east Texas, herbage yields per acre were 800 pounds or more in the open, but they decreased to about 100 pounds per acre in a curvilinear relation with increasing tree cover. Pinehill bluestem, one of the most important cattle forage species in the mid-South, contributed most to herbage where trees were sparse and gave way to unpalatable longleaf uniola as timber stands increased. In the other instance, two-eyed berry, a good winter deer forage plant, was scarce in the open but was the most frequent herb beneath dense timber. Consequently, the reduction in grazing values with increased overhead cover may be more critical for cattle but less critical for deer than that indicated by the reduction in herbage weights. These relations illustrate that timber stand statistics can provide a practical means of predicting forage yields, which in turn indicate carrying capacity for livestock and game. Thus, a knowledge of timber-forage relations serves as a practical tool in the coordinated management of these two forest products.

From 1962 to 1964 the sagebrush defoliator (Aroga websteri) caused extensive sagebrush mortality on millions of acres in northeastern California and neighboring States. While Aroga is a native insect and earlier outbreaks have occurred, too little was known to be able to determine how long the outbreak would continue or the extent of the damage--or even whether there was damage, since this depends on one's viewpoint. Where a perennial grass understory exists, sagebrush mortality improves livestock range conditions by releasing the grass, thus serving the same purpose as chemical herbicides. Where a native grass understory is lacking on livestock range, agencies can prepare for large-scale grass seeding and thus take advantage of the sagebrush mortality if the dynamics of an Aroga outbreak are known.

The picture on important game ranges is different. Here, sagebrush mortality may cause serious problems for deer, antelope, and sagehens. The most serious impact of the current Aroga outbreak is on the winter range of the Devil's Garden deer. Aroga has killed sagebrush on extensive areas of this range where sagebrush is important for the maintenance of the deer herd.

Except for winter game ranges, the overall impact of this infestation is not believed to be serious. It is unlikely that the sagebrush defoliator will completely eliminate sagebrush over vast areas. Even where defoliation is complete, a few sagebrush plants will survive to aid in revegetation. Even where sagebrush is seriously damaged, sagebrush mortality is usually spotty--with patches ranging from a few hundred to several thousand acres. Because of the many acres of land covered by sagebrush, the percentage of the area denuded is relatively small. Knowledge gained in study of Aroga is expected to aid land managers in making decisions on control programs in the event of a future sagebrush defoliator outbreak, which is almost certain to occur.

3. Evaluation of Wildlife Habitat

The value of various habitats for the production of wildlife can be estimated in a number of ways. Quantities of herbage, mast, and berries, and their chemical composition are important indicators of productivity, especially if food preferences and requirements for various species of wildlife are known. Likewise, actual observations on use of food and cover can provide information on habitat value. However, reliable methods for measuring and sampling forage production and utilization must be devised before adequate appraisals can be made.

a. Quantity and quality of forage. A survey of trees and shrubs which produce fruits eaten by wildlife was made on National Forest lands in the Missouri Ozarks. Dogwood (Cornus florida), sassafras (Sassafras albidum), fragrant sumac (Rhus aromatica), and dwarf sumac (R. copallina) were the most abundant fruiting species. Seventeen other species also produced fruits eaten by wildlife. The greatest variety and density of fruit-producing species occurred in the bottomland hardwood type. However, none of the fruiting species had a high percentage of plants with fruit. Abundance and fruiting were influenced by crown cover of overstory trees, aspect and position on slope. This study helps define future research efforts to improve wildlife habitat on Ozark forest lands, especially for white tail deer and turkey.

Estimates of wildlife habitat values could be made more rapidly if wildlife food production could be predicted from information available on forest type maps which are brought up to date every 10 years. Work done in cooperation with the Wisconsin Conservation Department and with the Chequamegon, Hiawatha, and Nicolet National

Forests indicates that winter deer browse production in the northern hardwood type can be predicted within reasonable limits, especially if recent cutting history is known. Average browse production for this type on the three forests was very low--7.6 pounds per acre. Some influence of soil type was noted in that stands on the sandy soils in the Hiawatha National Forest averaged 4.2 pounds per acre, while those on the loamy soils of the Nicolet produced 6.4 pounds, and the stands on the Chequamegon produced 12 pounds.

Browse is a major source of deer forage in the 193 million acres of southern forests. The season in which the browse plants grow and in which green growth is available has a direct bearing on their usefulness to the deer herd. In east Texas shortleaf-loblolly pine-hardwood forests it was found that, after rapid growth in early spring, twig elongation practically ceased for 12 of 16 browse species. A few species responded to increased moisture and grew through the summer, and two continued on into fall. Most vines died back somewhat in late summer and fall. These differences in growth patterns emphasize the need to have a variety of browse within deer's home range so that they can have access to young green growth through most of the year. Fruiting time of browse further illustrates the periodicity of food supply. Most species set seed in the fall, when acorns are ample. Five species--muscadine (Vitis rotundifolia) and summer grapes (Vitis aestivalis), fringetree (Chionanthus virginicus), sassafras (Sassafras albidum), and American beautyberry (Callicarpa americana)--fruited during the summer. Thus, their importance is enhanced by their fruiting at a time when other nutritious game food might otherwise be scarce.

A preliminary examination of plant frequency data collected from 500 transects on 100 plots and distributed fairly uniformly throughout the flatwoods of north Florida and south Georgia has provided some interesting and useful observations on principal differences between three understory types (wiregrass, gallberry, and sawpalmetto) for quail, turkey, and deer. Generally, it appeared that flatwoods communities might be most productive for quail and turkeys, but less for deer. Of the subtypes examined for quail, it appeared that wiregrass (Aristida stricta) and sawpalmetto (Serenoa repens) were about equally productive, and the gallberry (Ilex glabra) type apparently was much less productive. A similar situation was seen for turkeys, except that the palmetto type appeared more productive for turkeys than the wiregrass type; and again, gallberry was the least productive. Though all types were apparently marginal for deer, there were significant differences in the three major understories; and the wiregrass and palmetto types appeared to be somewhat more productive.

Clipping studies conducted in western Montana show that the average serviceberry plant produces only 16.3 grams of new twig growth per year. Feeding at random, a deer would have to utilize 100 percent of the annual growth on 111 plants to obtain its daily requirement of 4 pounds. Feeding selectively on mature plants and utilizing only 60 percent of available forage, one deer still requires 67 plants a day to get through the winter in prime condition. This finding could have major significance in determining habitat management plans for browse ranges. Despite serviceberry's status as a preferred food, it would be impossible to grow enough serviceberry to support all of Montana's deer. Thus, where a highly productive range is required, it may be desirable to favor a less palatable but more productive species than serviceberry.

In Oregon, analysis of bitterbrush samples taken in mid-September showed significantly higher percent ash and nitrogen-free extract and lower percent crude fiber content under the natural stand of pine than under the thinned stands. There

appeared to be a consistently higher level of crude fat under the natural stand as compared with the thinned stands, although the differences were not significant. Crude protein content did not vary significantly in this study between the shady, natural pine stand and the more sunny, thinned stands. There were no significant differences in nutrient groups between thinning treatments.

In the Black Hills of South Dakota, however, chemical analysis showed Kentucky bluegrass (Poa pratensis) and some associated species contained more nitrogen-free extract and less crude protein, crude fiber, calcium, and phosphorus where growing without the influence of shade. Both range types appear to be nutritionally adequate for livestock and game during the summer grazing season. If grazing methods could be developed to make better use of potential forage occurring under the trees, livestock income from Black Hills ranges could at least be doubled.

b. Habilitat utilization. Based upon counts of accumulated droppings, deer, elk, and cattle each use openings in spruce-fir forests of Arizona in a different manner. Cattle use openings more than adjacent forest, elk use was about the same between the forest and the openings, and deer preferred the forest borders. Cattle made more use of natural than created openings; elk and deer did not. Openings larger than 20 acres were used little by deer and elk, except near forest borders. All sizes of openings and creation of small openings by cutting should improve deer and elk habitat.

In the more open ponderosa pine forests, comparative use by deer, elk, and cattle of the natural openings and adjacent, selectively cutover forests was different from the dense spruce-fir forests as determined from counts of accumulated droppings. Deer used the forest and openings at about the same intensity. Elk and cattle used the openings more than the forests. Greatest numbers of elk and cattle dropping groups were in areas where perennial grasses were most abundant. Deer use was more strongly associated with an abundance of forbs. Cattle used all sizes of forest openings with about equal selectivity. Deer and elk preferred openings less than 1,600 feet across (46 acres for a circular opening). These findings suggest that natural openings in the ponderosa pine forests should be maintained, clearcutting should be less than 1,600 feet across, and that reseeding logging disturbed areas to perennial grasses for elk and cattle, and forbs for deer, would be most desirable for coordinating timber cutting with habitat management.

Do deer concentrate on areas of particular soils? This question was studied in the North Coast region of California in the oak-grass type. Earlier work here has shown that cattle prefer forage produced on specific soils, namely, in decreasing order of preference: Yorkville, Laughlin, Kneeland, and McMahon. Pellet group counts and animal observations showed that deer preferred forage from these soils in the exact same order. This does not mean that soils are the sole determining factor for deer distribution. Exposure, microclimate, range condition, and other factors all play a part. But soils do apparently exert an important influence on deer distribution. Studies of soil-deer relationships in the North Coast region will be continued and extended to brush and timber types.

In Oregon, the pattern of carbohydrate accumulation-depletion was determined for tops and roots of bitterbrush (Purshia tridentata), an important big-game browse plant, with findings on percentage and weight distribution of mobilizable carbohydrate. Seasonal trends in both percent and weight of total available carbohydrate compounds were cyclic for all portions of the plant. Carbohydrate accumulations declined during the early growing season and reached an extended period of low

percentage and weight during the rapid twig growth and seed formation stages between mid-June and mid-August. Following this period, reserves began to build up, continuing until leaf fall and thus restoring carbohydrate accumulations to a high point a little above their prevernal level. The study results are considered important to management of big-game habitat in Western United States where bitterbrush extends from New Mexico to British Columbia.

Preliminary data collected on grassland habitats in South Dakota used by sharp-tailed grouse indicated that this species preferred a variety of habitat types. Short grass and mixed grass communities were used for courtship displays. The mixed grass areas were used mostly for feeding and cover in early summer. Shrub types were used for these activities more during late summer. Slightly more than one-half of the fall grouse observations were made on cropland. Short grass areas were used again in the fall for display activities. Cropland remained a favored type throughout the winter. However, tree and shrub types were also important during this stress period.

c. Vegetation measurement and sampling. A simplified and objective procedure for estimating browse yields is needed to speed up forage inventories in the 193 million acres of commercial forest lands in the South. A recent study in upland forests of east Texas showed that total twig length was closely correlated with yields of deer browse plants, but the best predictor of yields was a combination of twig numbers and length. The twig-weight relation offers several advantages. It is more objective than visual estimating, is less time-consuming and expensive than clipping and weighing samples, and permits repeat measurements on the same plant.

Likewise, bitterbrush twig data from two sites on deer winter range in southern Idaho show consistent relations between twig diameters, lengths, and weights. Twig diameter accounted for approximately 50 percent and 80 percent of the variation in length and weight, respectively. Average length or weight of twigs on a site probably can be estimated within about 10 percent of their actual means with a stratified random sample of 30 twigs. Twig weight was highly correlated with length ($r = .86$) and with diameter + length ($r = .95$). Although not of value in estimating browse utilization, both the latter relations provide a basis for estimating twig production on areas where removal of twigs is undesirable. Analyses of data from the same and additional sites for several years should indicate if development of a field method for measuring browse utilization is feasible.

In western Montana, studies of the relationship between numbers of twigs browsed and total utilization show a high correlation on both serviceberry and chokecherry. At any utilization level below 60 percent, there is a direct linear relationship between the percentage of twigs browsed and the percentage of twig length removed. Using this information, it is possible to obtain reliable estimates of browse utilization during winter with a single count of browsed and unbrowsed twigs in the spring. The potential reduction in manpower required to obtain utilization information is considerably greater than 50 percent because tagged twigs are not needed and counting is considerably faster than actual measurement of twigs.

The animal carrying capacity of pastures and ranges is often determined by clipping and weighing forage yields on small randomly located plots. Plot yields vary widely, and thus the sampling process is time-consuming. Consequently, the precision of sampling frequency falls below acceptable levels. In a pine-hardwood forest of east Texas ranked-set sampling was considerably more efficient than random sampling for estimating weights of browse and herbage. The procedure was to establish sets of three closely grouped quadrats, visually rank quadrats within sets as highest,

intermediate, or lowest in forage weight, and then clip and weigh forage from one quadrat of each set.

For browse plots, the variance of the mean of ranked quadrats was about half to that of the unranked quadrats. This infers that precision equal to that of random sampling could have been achieved with half the number of clipped quadrats. Ranked plots also improved efficiency of sampling herbage but not quite in the same proportion as for browse. The increase in efficiency, as implied in this test, would result in great overall saving of time in evaluating livestock and wildlife potential of the 193 million acres of southern forests.

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III. FOREST PROTECTION RESEARCH

A. FOREST FIRE

Problem

In the United States more than one billion, one hundred million acres of forest and watershed lands require protection from fire. Each year, depending upon several critical factors of risk, hazard and weather, some 100,000 to 175,000 fires occur on these lands. Private, State and Federal fire control agencies spend an average of 150 million dollars annually to control these fires. Fire damages amount to a much larger sum.

From the beginning of organized forestry and conservation programs in the United States, forest fire control has been a dominant consideration. Significant progress has been made in reducing forest fire losses. Through research and development activities and energetic action programs by many agencies effective methods have been developed to prevent, detect and suppress forest fires. This progress has been fundamental to the successful practice of forestry and to safeguarding of priceless natural resources.

While progress has been substantial, forest fire control remains as a critical requirement in natural resource development and conservation. Nearly every forest region of the Nation has combinations of forest fuels, topography, weather and fire starting agents which make forest fires a continuing threat. Periodically the factors influencing the start and spread of forest fires occur in critical combinations. The result is well known--expensive conflagrations, loss of life, damaged industries, and communities, silt laden streams, blackened, ugly forests of drastically reduced value, and costly rehabilitation measures.

The forest fire problems will not go away. In one month of the current year, fire losses on the national forests exceeded the total losses for the entire year of 1965. The problem will continue to grow. A growing population will place steadily increasing demands on all forest resources. Some 80 percent more timber products must be available by the year 2000. Forest recreation use will more than double in the next ten years. Similar increases will occur in demands for water, forage, wildlife and other products of the forest. All of these things are affected by forest fires.

Population pressures are changing the nature and increasing the complexity of forest fire problems. Expansion of many cities into surrounding forests means that fires today often involve homes and developed areas as well as wildland vegetation. The safety of people is of major concern. More people in forest areas also brings much greater exposure to human sources of fire ignition. Fire hazards are increasing. Thousands of acres of coniferous plantations have reached the critical stage for susceptibility to crown fires. Vast watersheds which must remain covered with vegetation to prevent erosion are breeding grounds for conflagration fires. Accelerated cutting of timber to meet forest product demands is creating an increasing problem of logging slash disposal. Requirements for abatement of air pollution are dictating that new techniques be developed to reduce the smoke nuisance from prescribed fires.

Solutions to the forest fire problems of today and tomorrow must come primarily from a stepped up research program. Only through development of new knowledge and more effective technology can continuous fire control progress be achieved.

The opportunities for forest fire research to make significant contributions are greater than ever before. General advances in many scientific fields can be developed through the fire research program for specific application to forest fire problems. On the horizon now are a forest fire intelligence system utilizing computers to analyze pertinent data on fire behavior and control, an airborne electronic fire detection system, prevention of lightning fires through special weather modification techniques, new systems for faster, more effective fire attack, and improved methods for fire prevention and hazard reduction.

USDA and Cooperative Programs

The national program of forest fire research is performed by the Forest Service in cooperation with private, State and Federal agencies and universities. A major part of the research is performed at three Forest Fire Laboratories located at Riverside, California; Missoula, Montana; and Macon, Georgia, equipped with special facilities and manned by an interdisciplinary staff.

Forest fire research projects are also currently headquartered at College, Alaska; Seattle, Washington; Berkeley, California; Flagstaff, Arizona; St. Paul, Minnesota; Columbia, Missouri and State College, Mississippi. These projects are closely associated with programs at the Forest Fire Laboratories. They strengthen both national and regional programs through utilization of facilities and cooperative assistance available at these locations and the surrounding forest regions.

Federal agencies cooperating in the forest fire research program include the National Science Foundation, Environmental Sciences Service Administration, National Park Service and Bureau of Land Management. Much of the research has strong national defense aspects. Department of Defense agencies cooperating in the program include the Office of Civilian Defense, Advanced Research Projects Agency, Defense Atomic Support Agency, U. S. Navy and U. S. Air Force. Several universities and state forestry departments also provide personnel, study areas, and specialized equipment. The states of California, Georgia and Missouri make direct financial contributions to the fire research program.

In fiscal year 1966 forest fire research provided 79 professional man years of in-house effort. In addition 4 professional man years were financed by Forest Service funds for fire research by universities and other research institutions. This domestic program was supplemented by PL 480 funds in 2 countries totaling 43,274 U. S. dollars equivalent.

Progress - USDA and Cooperative Programs

1. Fire Physics and Chemistry

Fundamental research investigations at the three forest fire laboratories continue to increase our understanding of the mechanisms by which fires are ignited and spread. Although such research is slow, painstaking and undramatic, it offers our surest hope for achieving radically new improvements in the science of fire control.

Measurements of fire phenomena always require the analysis of a large number of variables. To reduce the number of variables which must be considered, and thus to reduce the cost of these studies, the Northern Fire Laboratory at Missoula, Montana has developed a technique for preparing uniform, reproducible mat-type fuel beds. By this means of controlling such fuel factors as density and porosity, both the

number of repetitive trials required and the time needed to analyze the results of each trial can be greatly reduced. This more efficient research is accelerating wind tunnel and combustion laboratory experiments of fire phenomena. The results are providing a basis for writing the equations of fire spread and intensity.

Along the same lines, the Fire Chemistry project at Berkeley, California, has discovered that glucose can be substituted for the highly refined (and very expensive) alpha cellulose previously used as a standard for testing thermal behavior in wood type fuels. This is a significant development in advancing experimental technology for gaining a better understanding of complex chemical and physical factors in forest fires.

In another technical breakthrough, the scientists at the Northern Fire Laboratory have succeeded in planting temperature sensors inside single pine needles to record the fuel temperature changes that take place as a fire front approaches. This achievement represents not only a very clever piece of instrument miniaturization, but also a very practical means of determining the relative effectiveness of radiant versus convective energy in preparing fuels for ignition.

Studies of experimental fires in the wind tunnel at the Southern Fire Laboratory have exploded one of the firefighters oldest rules of thumb: that the effects of slope and wind are identical and interchangeable. It now appears that slopes less than 30 percent have little effect on rate of fire spread; between 30 and 40 percent slope becomes an increasingly effective factor, and slopes greater than 40 percent will greatly accelerate fire spread. Wind, on the other hand, becomes effective as soon as its velocity is strong enough to overcome the fires natural buoyancy, and its effects are nearly constant throughout the normal range of wind speeds encountered on wildland fires. These findings will have important applications in planning fire control strategy, and particularly in planning for prescribed burning operations.

The fire chemistry project at Berkeley, California, has made further strides in untangling the complex series of chemical reactions which determine whether wood fuels will burn by flaming or glowing. We need to know these reactions in order to design "tailor-made" fire retardants that can act effectively at the proper stage of the combustion process. At present, many of the most effective flame suppressing retardants produce charring and glowing at such low temperatures that the total damage to treated wood materials exposed to a small fire may actually be greater than that to untreated wood. The specific discovery in 1966 is that the fork in the road to flaming or glowing occurs at a temperature between 200 and 400 degrees centrigrade when one of two competing endothermic reactions occurs. The one leading to flaming is an "unzipping" reaction which produces 1,4-anhydro-α-D- dluco-pyranose. The one leading to glowing is a dehydration process, the intermediate products of which have not yet been identified. This news will probably excite you now only if you are a chemist, but may lead later to very practical applications in forest fire control.

2. Atmospheric Physics and Forest Fire Meteorology

Forest fires and weather are inseparable partners. Atmospheric variables influence every aspect of the fire control job from fire prevention through all phases of fire attack and suppression. Current research is concentrated on atmospheric physics applications to the lightning fire problem and studies of the weather patterns creating critical fire behavior situations or optimum situations for the prescribed use of fire.

Lightning

Project Skyfire at the Northern Forest Fire Laboratory achieved several significant advances in lightning fire research. The third year of a long range experiment aimed at determining the possibilities of preventing lightning through cloud seeding was completed. The box score for the experiment, being carried out in cooperation with the National Science Foundation, shows more than 30 percent fewer cloud-to-ground lightning discharges from seeded storms. A statistical test of the null hypothesis of no difference in frequency of cloud-to-ground lightning shows a significant level of 0.23 for a two sided test if all no lightning days are excluded from the data. Approximately 5000 lightning discharges recorded during the experiments were used in the evaluations.

The lightning experiments are being continued to obtain a larger number of samples of treated and untreated storms and to investigate specific effects of very heavy silver iodide seeding on the type of discharges most likely to ignite forest fires. This discharge, identified by Project Skyfire research, has the special feature of a long continuing current portion with continuous charge transfer occurring for some 200 milliseconds. Work is underway to investigate the possibility that the frequency and duration of this apparently important fire starting lightning discharge may be altered by cloud seeding.

Significant advances have been made in the instrumentation for lightning experiments. The experimental field area at Missoula now contains a network of electrostatic field change sensors, photocell devices for sensing luminosity, sound distance units to record thunder transit time, automatically triggered cameras to photograph discharges and a rotating optical system to fix the direction of discharges. All sensors transmit to a multi-channel magnetic tape recorder. Two radars in the experimental area fix the location of cloud systems and make a vertical probe through individual cloud cells. In addition, the U. S. Weather Bureau Point 6 radar on a nearby mountain peak monitors cloud systems over a radius of 250 miles and transmits this information directly to relay scopes in the forest fire laboratory. This unique instrument system permits the detailed surveillance of atmospheric factors in a 300 square mile test area, and records the location, duration, intensity and electrical characteristics of each lightning discharge.

Laboratory experiments that provide a new understanding of methods for modifying the electrical structure of clouds with freezing nuclei were performed at Missoula in 1965. These experiments investigated the effects of waterdrops and ice crystals on the sparking potential of air within a simulated cloud environment. It was found that the sparking potential associated with waterdrops is a square root function of drop radius but independent of pressure; with an ice crystal the sparking potential is a linear function of pressure, but independent of crystal size. The sparking potential of an ice sphere is a function of both particle size and air pressure. Wet ice spheres have a sparking potential similar to waterdrops. The experiments showed that irregular ice crystals lower the sparking potential across a gap by 35 to 40 percent. These results give further insight to the potential for altering electrical characteristics of clouds through seeding with ice forming nuclei.

Fire Weather Patterns

At the Riverside Forest Fire Laboratory a new system has been developed for predicting the incidence, severity and duration of critical fire weather. This research, performed in cooperation with the Department of Defense, shows how fire weather types can be used in identifying levels of fire danger. The results indicate that factors other than normally used pressure patterns must be considered in characterizing major fire weather types. These include antecedent weather, the moisture associated with frontal passages and season of the year.

The fire weather pattern descriptions developed by this project can be used in all regions of the United States. They provide a basis for utilizing a nationwide network of 89 weather stations in identifying specific fire weather situations. Tables utilizing data from these stations present (1) the frequency of occurrence and duration of each fire weather type by months, and (2) the central tendency, ranges, and measures of variation of weather parameters and fire danger by months for each station. Use of these guides can mean increased efficiency in fire weather and fire behavior forecasts and substantial savings in fire control costs.

At the Southern Forest Fire Laboratory a new research program has been organized in cooperation with the U. S. Navy to investigate atmospheric behavior in a forest area at a land-sea interface. An initial network of 20 automatic recording weather stations is being installed in an experimental area at Ft. Stewart near the Georgia coast. Later, an additional network of 20 stations will be installed. In addition to meeting the specific military interests of the Navy, these stations will provide data for studies of several important fire weather factors. These include the small-scale climatology of fire danger parameters, fuel moisture variation at a land-sea interface, relationship of small scale meteorological events to large scale weather patterns, and small-scale variation in meteorological elements and their relationship to fire danger during periods of seasonal drought in the eastern United States.

3. Fuels and Fire Behavior

Fuels

One of the biggest barriers to accurate predictions of how a given forest fire will behave and how much fire fighting force will be needed to control it is lack of understanding of the composition and structure of the fuels in which it burns. At all three forest fire laboratories, studies are underway to improve our ability in fire behavior prediction.

The relationship between relative humidity of the air and the moisture content of various species of hardwood leaves has been investigated at the Southern Fire Laboratory at Macon, Georgia. The results confirmed what firefighters have long suspected: there are marked differences between species even at the same relative humidity. The studies also found something unsuspected. Hysteresis loops vary widely among species too. The hysteresis loop is a measure of the difficulty with which a fuel absorbs or loses atmospheric moisture. This finding is not a pleasant one, since it adds another complicated factor to an already complex problem. But taking hysteresis into account will enable much better predictions of fuel flammability during the early stages of drought.

For the past two years fuel studies at Missoula have concentrated on "flash" fuels: those grass species that dry out early in the year and permit fires to spread rapidly and involve large acreages. Visual keys have been developed so the current flammability of cheatgrass (the worst fire type) can be recognized and fire plans adjusted before critical conditions occur. Now this work is being extended to Medusahead, a range type that is slightly less flashy than cheatgrass, but one which has been an increasing source of rangeland fires in the west.

Mass Fire Behavior

A mass fire behavior research program is sponsored jointly by the Forest Service, the Office of Civilian Defense, and the Defense Atomic Support Agency. The program conducted its two largest test fires in 1966. A forty acre fire burned 6400 tons of fuel in the winter when fuels were wet. A comparison test was made in June with extremely low fuel moistures. Designed to measure the factors that contribute to the development of firestorms, each test produces several miles of data on punched tape. Translating these records into accurate pictures of the wind and temperature fields, patterns of radiative and convective heat loss, and chemical gas analysis requires a highly sophisticated electronic data processing system. Perhaps the most significant finding from the data analyzed so far is that temperatures in these larger fires are much higher than previously suspected. Where fires were burned at low fuel moistures temperatures above 2000 degrees were recorded 20 feet above the fuel bed and the temperature within the flame zone exceeded 3000 degrees.

The mass fire staff also completed investigation of an unscheduled firestorm. On March 7, 1964, near Santa Barbara, California, a fire tornado developed during the course of an 800 acre brush fire. This fire whirlwind cut a mile long path across the countryside, injured 4 people, destroyed 2 houses, a barn, and automobiles, and wrecked a 100-tree avocado orchard. A careful analysis of the fuels, weather and topography has isolated several factors that appear to be critical to firestorm formation. These are: atmospheric instability at both low and high levels; low ambient wind speeds; strong wind sheer near the surface; light, but fast burning fuels; and a topographic configuration conducive to eddy formation.

4. Fire Prevention and Use of Fire

Man-Caused Fires

Fire prevention research in the West and South continues to provide important clues on how to sell fire prevention. Benchmark studies in Butte County, California and Louisiana were both completed this year.

Of particular importance to the fire prevention problem is a relatively small number (about 2 percent of the population) who, although they are frequent users of the wildlands, have little knowledge of proper fire use and are indifferent to the problem. They were even younger than the other frequent users. Females were equally represented. Their low level of schooling for their age indicates a high proportion of dropouts and retardations. If not still in school, they tended to have low-paying, part-time jobs.

It has been estimated that fire agencies need to spend about $37.50 in fire prevention funds per person in the Butte County area in order to establish a satisfactory level of prevention effort in reducing accidentally started forest, brush, and grass fires. Research has now identified the 10 percent of the 60,000 population who are high risks or live in high fuel hazard areas. On this high risk, high

high hazard group we would plan to spend $37.50 per person in fire prevention funds. For the remaining 54,000 we would plan to spend only $2.50 per person in order to maintain their favorable fire prevention attitude. This same principle could be applied to other highly hazardous wildland areas in the United States.

Results of interviews from a selected ranger district on a Louisiana National Forest, noted for high fire occurrence, provides detailed information on the beliefs, characteristics, and attitudes of the people. In 1941, 70 percent of the people had beliefs unfavorable to fire regulations. The present study showed over two-thirds are now favorable. Cattle owners are still largely unfavorable to fire prevention.

These findings indicate some measures that should help fire control organizations prevent fires. They are: (a) heighten public consciousness that fire prevention is a public concern and not just Forest Service business; (b) emphasize Forest Service commitment to multiple-use management of National Forests; (c) aim prevention efforts at an audience characterized by older, less well-educated persons with little experience outside of their isolated environment; and (d) build up the ranger in terms of community esteem.

These findings, although particularly applicable to the study area, will be useful to fire administrators in orienting their prevention activities anywhere in the South.

Use of Fire and Hazard Reduction

Turning from fire prevention to fire use, research in 1966 has concentrated on improved methods to deal with the tougher hard-to-kill brush species.

Palmetto-gallberry has always been a problem in the South because its vigorous resprouting characteristics require two or more repeated burns in order to suppress enough plants for pines to compete successfully. If the first burn is hot and clean burning, insufficient fuel is left to carry fire the following year. On the other hand, light burning in heavier fuels does not create the groundline temperatures needed to kill the plants. Now, new firing techniques have been developed for use under selected weather conditions to produce time-temperatures equal in intensity to those produced by heavier roughs under less desirable conditions. It is possible, therefore, to create necessary temperature conditions on repeat burns without the dangers usually associated with heavy fuels. Knowledge of fire temperatures and their prescription requirements are prerequisites to the prediction of fire behavior and fire effects under varying weather conditions.

Effective herbicide treatments are needed for controlling brush regrowth on timber plantations in California to allow survival and rapid growth of planted coniferous trees. Three years of effort have gone into finding the best site preparation and brush control treatments that do the least damage to pines. Basic recommendations, after mature brush has been removed mechanically or by fire, are: (1) apply an initial spray and two follow-up sprays to sprouting brush in most situations; (2)the initial spray, either as a site preparation spray or a plantation-care spray should be applied as soon as a full brush stand is established; delay beyond one growing season should generally be avoided; (3) the first follow-up spray should be two years after the initial spray, unless initial spray results were poor and then it should be the following year; a third spray should be delayed until a new crop of seedlings is 1 to 2 years old; (4) pine planting should be delayed until a site-

preparation spray has been applied, especially on burned sites; (5) apply site-preparation spray near the end of the active plant growing season but ahead of drying soil conditions or freezing weather; (6) spray brush on pine-planted areas soon after, but not before, pine buds have grown to full size and hardened. Such a program will allow pine plantations to develop whereas previously they usually reverted to brush.

A major study on prescribed fire planning was completed at Missoula in 1966. The published results provide guides for when and how to burn logged-over land in the Intermountain west. Sixty two fire specialists with more than 700 seasons of experience in prescribed burning contributed to the development of planning techniques evaluated in the study. Prefire preparations, season and date of burning, necessary fuel and weather conditions, ignition patterns and control procedures are outlined. Topographic models are used to illustrate typical situations for planning prescribed fire operations.

Slash Studies

What to do with logging debris has been a problem since the first American pines were cut for masts for the British Navy. So far the only practical solution has been to burn, but growing concern over the risks, costs, air pollution and aesthetic problems of slash burning is putting more emphasis on research. We are trying to find ways to burn slash more safely, rapidly and cleanly. At the same time we are exploring possible alternatives to burning.

Slash tables have been developed at the North Central Forest Experiment Station for predicting how many tons of logging debris will be left in shortleaf pine forests after the trees have been thinned out for better growth potential. The necessary measurements are normally made during thinning operations, so that little extra effort is required to estimate the fuel weights. Slash tables are useful for determining which methods of slash disposal to use and also for determining the fire hazard created by these thinning operations.

Coating slash with asphalt or wax emulsion to keep it dry for burning in the winter has shown promise in California. Coatings applied during the summer when the fuel moisture of the slash is low permits burning in early winter even after five inches of precipitation has occurred. For areas like California where the usually safe burning season is very short, asphalt provides fire control managers with additional time to cope with hazardous slash areas.

Field and laboratory tests of a chemical slash dissolver were conducted to determine possible acceleration of slash decomposition. Successful chemical disposal would eliminate the hazards connected with the use of fire for slash disposal. Results after one year indicate some differences in the field between treated and untreated samples. However, a laboratory study detected no decomposition effect. For the present, fire will still have to be relied on as one of the chief agents in this work.

One variation in the use of fire in slash disposal is a portable slash burner. Such a portable burner was constructed and tried on debris left from a thinning operation and on brush piles. Even wet slash was consumed as rapidly as a small fork-lift equipped tractor could dump 1/2 to 3/4 ton piles into it. This opens the possibility of burning slash that is too wet to burn any other way, and also burning during periods when open burning of piled slash is too hazardous.

Another aid to the disposal of slash is the use of fire retardant chemicals. For large logging areas that cover several acres, such as in clear cut blocks, the slash can be lightly treated with the retardant to reduce the rate of fire spread. This technique not only reduces the rate of fire spread by about ninety percent, but also reduces the number of spot fires by about two-thirds. This, again, can mean a longer burning season for fire control managers.

5. Fire Control Methods and Systems

For the first time since the CCC conducted field tests in 1938, measurements have been made on the rate at which crews can build fire lines. The 1938 field tests produced information on how much manpower is needed to build a fire line in a given amount of time in various types of fuel and topography. An attempt is now being made to find a procedure for updating the results of those field tests to fit recent changes in fire fighting methods. This new information is needed to determine manpower requirements for successful initial attack on fires.

The Forest Fire Laboratory at Riverside, California has also produced a Helitack Manager's Guide. This guide brings together under one cover the results of research on the use of helicopters in fire control and management. Fire control managers now have a basic reference for wildland helicopter operations.

One very important item left out of the Helitack Manager's Guide is the use of helicopter at night. Helicopters are restricted to flying in daylight hours due to the lack of proper lighting and guidance equipment on fire control jobs. Researchers in California have started a study that will develop many of the operational procedures for night flying. This is dependent, of course, on the concurrent development of lighting and guidance equipment. Using helicopters at night will almost double their value as a fire control tool, and should lead to earlier control of many wildland fires.

Scientists have analyzed the economic efficiency of an experiment in a full scale fire control system conducted on a forest management unit in California. This analysis showed that efficient fire control organization designed around a fuel break system was economically justified on the 40,000 acre Duckwall Conflagration Control Experimental unit on the Stanislaus National Forest. Costs of fuel break construction in timbered country are high. However, annual savings of $170,000 in timber fires and $119,000 in brush fires can be expected by using this full scale fire control system.

A system for using the Weather Bureau's new probability forecasts in determining the manpower needs for daily fire control management has been proposed by the Forest Fire Laboratory at Riverside, California. This system takes the guesswork out of manpower determinations by using guidelines similar to those used to produce actuarial insurance tables. Existing forecasts are modified by expressed probabilities of easier or worsening fire danger conditions. The forecasts will lead to more efficient use of available manpower in the fire control organizations.

Fire retardants are finding their place in the Southeast. The salt remaining in the tree crowns and surface fuels from a 300 gallon aerial tanker drop of unthickened, 13 percent monoammonium phosphate solution has stopped head fires in sand pine trees. Thus another tool has been found to help contend with the destructive crown fires in this forest type.

Fire retardants dropped out of aerial tankers have been suspected of corroding the aircraft's tanks. Corrosion can cause a jamming of the tank doors which would prevent the plane from ejecting its load. If the doors jammed at a critical time, it could very easily cause the loss of the plane and the life of the pilot. A team of inspectors from fire control agencies and chemical companies carefully inspected the tanks of twenty-six planes used in California during the 1964 fire season. The conclusion from this inspection is that flame-retarding chemicals with built-in corrosion inhibitors appear to be no more of a problem than jelled liquids such as Bentonite.

For lightning detection in the Northwest, sferics receivers were installed in Seattle, Washington and Medford, Oregon to track storms in the Montana and Idaho areas. This attempt to establish a lightning detection system received a serious setback when problems developed with the amplitude/distance correlation of these receivers and with the amplitude difference reception between stations receiving sferics from the same lightning stroke. Any other system of lightning detection would be prohibitively expensive. Therefore, work on this project will be suspended until technologies in the sferics field are improved.

Scientists at the Northern Forest Fire Laboratory have reported the results of the first three years of Project Fire Scan's airborne infrared fire detection program. The objective of this program is the evaluation of systems and techniques for the detection of incipient forest fires. This report presents qualitative correlation of probability of detection versus scanner aspect angle, timber type, and fire size. Aircraft patrol navigation requirements are also included in this report. An airborne infrared fire detection system could prove to be far more efficient and reliable than the fire lookout tower now in use.

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B. FOREST INSECTS

Problem

Insects continue to be among the most destructive agents affecting the Nation's forests, even as the forest lands themselves are becoming more valuable and their uses more numerous. Pressures for timber, water, wildlife, recreation, and esthetics are increasingly greater. This means more intensive forest management and more intensive and complete forest protection in the future. The losses that have been experienced in the past can no longer be tolerated.

Damage caused by insects is not confined to timber values alone: watersheds and wildlife habitats are impaired and fire danger is increased; insects destroy the seeds and cones of trees, thereby jeopardizing the success of seed orchards and natural regeneration programs; they infest browse plants, lowering their value to livestock and game; they damage or destroy huge quantities of forest products, such as logs, lumber, and pulpwood. Termites and wood borers invade dwellings; other insects infest shade trees and destroy scenic values in parks and recreation areas.

More and better information is needed on the causes of forest insect outbreaks, on the development of long-lasting silvicultural and biological control methods, and on the development and improvement of chemical controls that can be applied economically and without undue hazard to man, fish, wildlife, and other non-target elements of the environment.

USDA and Cooperative Programs

The Department has a continuing long-term forest insect research program involving forest entomologists as well as other researchers representing a broad range of the scientific disciplines. These scientists are engaged in basic and applied studies aimed at the development of safer, more economical, and more effective methods of reducing losses caused by forest insects. Research is carried out at the nine regional Forest Experiment Stations as well as at the Forest Products Laboratory; the effort totals 88 scientist man-years per year.

In addition, work is now being done under 14 grants for basic research (PL-934) at 10 universities and 1 research institute. In 1965, research was also being conducted under 22 PL-480 grants in 10 countries. These PL-480 studies included identification, collection, and shipment of forest insect parasites and predators, studies of the biology and ecology of pest insects and their parasites, and biology of certain insect pathogens. All of this research is closely related to the Forest Service program.

Cooperative relations in such forms as consultation services, land use, labor and facilities are in effect with many universities, state forestry departments and experiment stations, lumber and pulp and paper companies, and chemical companies. Agricultural Research Service cooperates in technical consultation on problems of mutual interest such as insecticides, insect identification, and in introduction of insect parasites and predators from abroad. The Canadian Department of Forestry also cooperates in the introduction of parasites and predators and participates in consultations on common problems.

One important change in Forest Insect Research facilities during 1965 involved discontinuing work at Beltsville, Maryland. The aerial survey methods project previously located at Beltsville was moved to Berkeley, California, to constitute part of a larger Service-wide remote sensing project there. The work on aerial application of insecticides will be continued under the leadership of Agricultural Research Service.

Progress - USDA and Cooperative Programs

1. Biological Control

Biological control involves the use of living organisms to combat pests. It generally implies manipulation of these organisms - natural enemies - by man, and may include the use of parasitic and predaceous insects, mites, nematodes, diseases, and vertebrate predators such as birds and rodents.

Biological control has great appeal in forestry; when successful it is cheap, effective and safe. However, for various reasons it is not applicable to every pest situation, and even at best demands long, hard, painstaking research. The following paragraphs illustrate some of the steps in the development of biological control techniques for selected forest insect pests.

a. Invertebrate parasites and predators. Little is known about the many insect and mite enemies of the different bark beetles or how to utilize them as effective biological control agents. The first approach to this or to any problem in insect ecology is to determine what organisms are involved and to evaluate their importance. Research on mites underway at Alexandria, Louisiana, has turned up almost 50 species, many new to science, found associated with bark beetles. Some of them are scavengers in beetle tunnels, some are predaceous upon other mites, and about 10 species are known or suspected predators of bark beetles. Members of the latter group suck the blood of beetle larvae and pupae or the contents of eggs. Future work will involve studying the life histories and requirements of the more promising of these mites and developing techniques for their mass production and release. Mites from other parts of the United States and foreign countries also will be investigated with a view to introducing species that are potentially useful predators and that are compatible with native ones.

For several years, foreign predators have been imported to the Southern Appalachians to help control the balsam woolly aphid in Fraser fir. The more important of the introduced predators continue to be recovered; however at this point is appears questionable that predators alone can prevent mortality of Fraser fir in the absence of other controlling factors. The relationship of insect attack to tree mortality also is not clearly understood, and studies to determine this are required.

A search for natural enemies of the balsam woolly aphid showed that lace-wing flies, predatory bugs, hover-flies and mites play an important part in the control of the pest in its native habitat. More detailed work on these and their relationships with the balsam woolly aphid, as well as search for additional beneficial insects, is underway.

In 1957 a program of importing and colonizing insect predators was undertaken in efforts to control the balsam woolly aphid in the Pacific Northwest. So far, 23 species of insect predators have been imported from Europe and Asia, and 5 of

these have become established. However, despite the sizeable populations attained by some of the predators in their new environment, control benefits have not been encouraging, and it appears unlikely that tree killing will be alleviated by predators introduced to date. The search is continuing for additional predator species that may combat the pest more effectively.

Parasite studies in Poland (PL-480), aimed at developing methods for manipulating Trichogramma embryophagum, an important egg parasite of sawflies, and at improving strains of parasite species are continuing. It was found that the life cycle of Trichogramma was synchronized with that of the sawfly host. It was also found that within-species crossing of strains of Dahlbominus fuscipennis and Dirhicnus alboannulatus, two important species of parasitic wasps, resulted in progeny with increased egg-laying potential. The information being gained is extremely useful in understanding within-species variation, an important feature in parasitic wasps.

A study was undertaken in 1965 at the Delaware Laboratory to determine the role of parasites and predators in field populations of the smaller European elm bark beetle, a vector of the Dutch elm disease. Prior to this, several shipments of the parasite Dendrosoter protuberans had been received from the ARS European parasite laboratory. A laboratory culture of this parasite was successfully established from the first shipment made from Europe in the fall of 1964, using the smaller European elm bark beetle as the host. Since then the parasite has been reared continuously with a new generation emerging every three weeks. Tests in the laboratory have yielded parasite-to-beetle ratios ranging from 1 to 1 to 1 to 19. Using single pairs of parasites per beetle-infested bolt there was an average emergence of 8 parasites in the F_1 generation. Controlled field releases were conducted in the summer of 1965, and D. protuberans was recovered.

Hypsipyla robusta is an important shoot-boring moth in India, and is a potential forest pest in some parts of the United States. Studies are underway under the PL-480 program to learn more about its natural enemies. Results to date have shown that H. robusta supports a fairly full range of natural enemies including parasitic flies, wasps and nematodes, as well as one species of predator.

b. Vertebrate predators. In California the black-backed three-toed woodpecker was demonstrated to be an important predator on the woodborer Monochamus oregonensis. Woodpeckers and other birds are generally recognized as predators, but the degree of their importance is difficult to evaluate. It is likely that additional attention will be given them in the future as biological control assumes a more active role in forest insect control operations.

c. Insect pathogens. Pilot tests of a commercial Bacillus thuringiensis (Bt) product (Thuricide 90 TS Flowable) were cooperatively carried out during 1965 in New Jersey and Pennsylvania against the fall cankerworm and in Connecticut and New York against the gypsy moth. Results of the test against the fall cankerworm showed that larval mortality, measured in drop trays, was directly related to dosage applied. Highest mortality occurred in areas given the highest dose and lowest mortality occurred with the lowest dose. Population reductions and residual populations due to Bt compared favorably with the conventional insecticide Sevin when adequate dosage was applied and the infested plot was thoroughly covered. Bt did not do as well as DDT, however. The test against the gypsy moth in Connecticut and New York gave different results, but neither achieved outstanding control. One of the most salient points to emerge from the analyses of these pilot tests is the difficulty of applying water sprays in general. The biologi-

cal effectiveness of Bt itself is not so much a problem as is the matter of gaining maximum deposit and coverage with water suspensions.

In an initial field test of Bacillus thuringiensis in Alaska, mortality of black-headed budworm larvae exposed to four different suspensions for a period of five days at field temperatures and humidities ranged up to 81 percent. Although it was previously known that black-headed budworm larvae are susceptible to thuringiensis in the laboratory, the results of the field test are important in that they show that it is still pathogenic to the budworm under the cold and wet conditions prevailing in the field in Southeast Alaska. Further refinements are necessary, but the outlook is encouraging.

In Colorado, two insect pathogens, a nuclear polyhedrosis virus and Bacillus thuringiensis, were tested against larvae of the Great Basin tent caterpillar. A combination of the two pathogens was found to provide more effective control than either one used alone.

Significant findings have been made at the Corvallis, Oregon laboratory on substances, in foliage of some trees, that are toxic to insect pathogens. As an example, material in Douglas-fir foliage inhibits Bacillus thuringiensis. Studies indicate that it may be possible to increase virulence of the insect pathogens by developing pathogen strains resistant to the antibacterial substances. So far some resistance has been developed in thuringiensis grown on material prepared from Douglas-fir foliage.

Investigations at the Raleigh-Durham laboratory, which were originally aimed at study of the causes for erratic effectiveness of Bacillus thuringiensis, have yielded information pertaining to the basic biology and mode of action of bacteria. They have shown considerable diversity among some B.t. gonidia in constitution, function, and developmental potentials, even among the progeny of a single cell. Gonidia arising from certain isolates may respond in manners entirely different from those of conventional forms of bacteria. These observations have brought the question of infectious processes into new light; and they suggest that many "atypical" forms of bacteria described in the literature might be derived from the gonidial stage of the same organism, and that all these developmental stages can be induced to transform into another form in one continuous succession of events. Observations also indicate that these bacterial developments seem to be subject to regulatory factors of outside origin, or possibly to genetic determinants of viral origin.

A significant discovery was made regarding a virus disease organism of the pine tussock moth. When polyhedral bodies were treated with a weak alkaline solution, the infective virus particle was liberated and increased mortality resulted from infection with this solution. This discovery may help in developing the use of this virus as a control agent.

Disease, particularly a virus, causes significant natural population reductions in the gypsy moth as density increases. The causative organism of these natural epizootics, a nuclear polyhedral virus, was used in an attempt to initiate an epizootic. 1×10^{12} polyhedra per gallon was applied by truck mounted mistblower at the rate of 4 gallons to the acre. One acre was treated. Marked differences were observed in the number of residual egg masses per acre in the sprayed and check areas; an average of 40 egg masses per acre were recorded in the treated area whereas 200 egg masses per acre were recorded in the check areas. Although the dosage used was extremely high and the treated area small, the successful population reduction to acceptable levels indicates the potential of this organism for control of the gypsy moth.

Grant-supported research at the University of Connecticut seeks to describe and evaluate all insect pathogens associated with gypsy moth larvae. The predominating types of pathogens identified so far belong to the genera Bacillus, Micrococcus, and Streptococcus.

In PL-480 research in Yugoslavia, work was continued on control of the gypsy moth with a polyhedrosis virus. Studies suggested differences in pathogenicity of virus strains obtained from different parts of the country. This work is continuing with emphasis on a search for potent strains and subsequent culturing of them.

At the New Haven, Connecticut laboratory, an unusual yellow motile Streptococcus was recovered and compared to known species of Streptococci; information was obtained on the pathogenicity of the organism for gypsy moth larvae. The recovery of this organism resulted from a continuing effort to identify the role of disease-producing organisms in the population dynamics of the gypsy moth.

At the Corvallis laboratory, cooperative research was undertaken with the Agricultural Research Service in 1965 to develop operational procedures for controlling the Douglas-fir tussock moth by aerial application of water sprays of a native polyhedrosis virus. Four phases of study were undertaken: (1) development of equipment for applying virus sprays, (2) spray performance under forest conditions, (3) methods and materials for evaluating virus spray deposits, and (4) effectiveness of different virus dosages and concentrations. These efforts were encouraging in that it appears probable that induced virus infection resulting from the application of 50 billion (50 times 10^9) polyhedra in one gallon of spray per acre against second instar larvae would result in complete collapse of the treated outbreak in the year of treatment. However, it also appears probable that all or nearly all of the current year's flush of new foliage might be destroyed before the epizootic could become effective. Applied early in an outbreak cycle of the tussock moth, a virus application would prevent major damage to the treated forest. Proof of these expectations will require operational testing following considerable additional research.

Trend studies with the nuclear polyhedrosis virus of the Douglas-fir tussock moth have indicated that the incidence of virus contamination occurring on the overwintering eggs may be indicative of the role the disease will play in the succeeding larval population. Surface sterilization experiments have demonstrated that the overwintering virus is on the surface of the eggs and not in the embryo. Egg contamination which infected as low as 15% of the hatching larvae was sufficient to initiate an epizootic and to nearly eradicate the insect population before pupation. Higher initial virus disease incidence resulted in faster development of the epizootic and less defoliation of the infested trees. These studies are continuing in an effort to develop a reliable method for predicting the effectiveness of the virus disease. Such a method would be of great value in determining the need for applied control measures.

Recent studies have shown that abnormal enzyme levels in blood plasma can serve as indicators of diseased conditions. These effects parallel similar changes known to occur in higher groups of animals.

The rate at which food passes through an insect determines the time the insect is exposed to pathogens in and on the food, and this exposure time may well determine whether the insect becomes infected. Furthermore, the same species of insect may pass food through the gut more rapidly when feeding on one host than when feeding on another. Thus different rates of pathogen application might be needed for treating the same insect feeding on different tree species. To get more background

information on this, the mean egestion (passing of food out of the gut) times were determined for two species of caterpillar. In these tests significant differences were recorded with larvae of different ages and larvae fed on different foods.

2. Chemical Control

While new control methods hold promise for the future, chemical control remains in most instances the most potent and reliable weapon in the fight against forest insects. Much of the present Forest Service research on chemical controls is aimed at developing safer insecticides. It searches for materials having "host-specificity", that is, insecticides toxic only to the target insect. It seeks insecticides that are effective without reliance on extended residual action. Good progress is being made, as illustrated by the following paragraphs.

Bark beetle control is usually achieved by spraying felled trees with insecticide to destroy insect broods within. Because the structure of the spray deposit is critical in determining how toxic the insecticide is to the insects, it is essential to know what governs deposit structure and how to control it. Research at Berkeley, published in 1953, led to the following main conclusions: (1) Lindane was the most toxic of a large group of residual insecticides tested. Dieldrin, endrin, and heptachlor were intermediate in contact toxicity, and DDT and dinitrocresol were the least potent. (2) The amount of insecticide applied for each unit area strongly affected deposit structure and toxicity. (3) The solvent had a marked effect on deposit structure. (4) Large changes in deposit structure were needed to make significant changes in contact toxicity; thus in practice considerable latitude can be permitted in the control of deposit structure without sacrificing the effectiveness of the material.

The standard procedure for suppressing the southern pine beetle is to fell infested trees and thoroughly spray the bark with a 0.5 percent benzene hexachloride (BHC)-diesel oil solution. By substituting water for oil as a carrier for the insecticide, there is a substantial saving in cost of the spray and transportation; also the risk of fire is eliminated, and workers' skin irritation minimized. In a summer study in Louisiana, a 1.0 percent BHC emulsion plus a wetting agent was found to be as effective as the 0.5 percent diesel oil solution. Each treatment gave 97 percent control. The 1.0 percent emulsion, however, was not so effective in winter. Estimated degrees of control were 81 percent for the emulsion and 97 percent for the oil formulation.

The systemic insecticide Bidrin was extensively tested in the Central States in 1965 for control of the smaller European elm bark beetle, vector of Dutch elm disease. The results obtained indicated that Bidrin did not provide protection against the beetle, either by killing or repelling it, and that as presently formulated and applied it cannot be considered wholly effective in preventing Dutch elm disease.

A new technique was developed for bioassaying American elm twigs for systemic insecticide residues. The conventional assay method for residual surface sprays (DDT and methoxychlor) is not applicable when organophosphorus insecticides (e.g., Bidrin and Thimet) are employed because of the more rapid metabolism of these insecticides in plant tissue as compared with those of residual insecticides. In this new technique direct results are obtained by using the smaller European elm bark beetle, the primary vector of the Dutch elm disease, as the assay agent. The beetles are confined on treated material; results are measured in terms of whether the treatment prevents the beetles from penetrating through the phloem into the xylem tissue, where disease inoculation occurs.

As a result of preliminary studies at Berkeley on approximately 60 different chemical compounds, it was found that carbamate and pyrethrin insecticides generally show a high order of biological activity against the spruce budworm, and are rapidly degraded within living systems. Further research on Zectran, one of the carbamate insecticides, has shown that it is effective against the spruce budworm at very low dosages providing it is properly distributed. These studies indicate that Zectran may provide one step toward the goal of insecticides that affect only the target organisms, and may offer a treatment that will not have the adverse effects experienced with DDT and other persistent insecticides.

Pyrethrin insecticides, made from plant products, are among the safest materials currently available for insect control. Some of these have been found to be extremely toxic to the spruce budworm and other forest defoliators in the laboratory, but they are too unstable in sunlight and air to be applied against these pests in the field. In 1965 chemicals were found that retard this breakdown, and field tests will be conducted with new stabilized formulations during the 1966 field season. When these formulations are perfected, they may provide effective chemical controls of forest insects that are safer to man and animals than any presently available to the wildland manager.

In the Lake States, alternative insecticides were tested against the jack-pine budworm. Malathion and Zectran, each applied by helicopter at the rate of 1 pound in 1 gallon of solution per acre, gave as good control as did DDT. Malathion applied at one-half pound per acre did not give satisfactory control, but Cygon at this dosage showed some promise. The test provided a basis for using Malathion instead of DDT in certain future jack-pine budworm control operations.

The present recommendation for systemic insecticidal control of the mimosa webworm on individual honey locust trees requires implanting measured amounts of insecticide concentrate into the tree trunks. Studies at Delaware, Ohio, have shown that the distribution of the material throughout the foliage of treated trees is significantly better when it is implanted into the roots. This is of interest to commercial arborists who are trying to improve the effectiveness of systemics without sacrificing economy and safety of operation.

A procedure recently developed at the Berkeley laboratory will aid in increasing effectiveness against the target pest, while minimizing side effects. Solid, insoluble fluorescent particles of microscopic size were suspended in test spray solutions. It was found that the number of particles that are carried by a given spray drop is in proportion to the volume of the drop. As these solid particles do not penetrate tissues and do not fade on exposure to the elements, and do remain where the drops hit, it is possible to determine the number and size of drops that hit target or non-target insects, plants or other elements of the environment. This development greatly facilitates studies now underway on the nature of spray distribution in forest areas treated with chemicals.

Experiments were conducted in California to test the effectiveness of insecticides for control of insects infesting cones and seeds of ponderosa pine. In one test 4 insecticides were applied as water emulsion sprays to individual cone clusters during the egg-laying period of the ponderosa pine seed moth and shortly before the attack period of the ponderosa cone beetle. Of these, Guthion and Zectran gave promising results against the cone beetle, while DDT and Diazinon were ineffective. None of the insecticides afforded significant protection against attack by the seed moth. In another experiment all the old cones in which the seed moth overwinters were removed from a three acre plot. Seed moth populations which developed in cones on trees within the cleared area

were not different from populations in cones in the surrounding area, indicating that clean picking or removal of old cones from small seed production areas is not likely to reduce infestations, and that further effort should be directed toward direct control by means of insecticides. These insecticide studies indicated that probably two insecticide applications per year will be required to protect ponderosa pine seed crops, since applications made late enough to give protection against cone beetles will be too late to control the seed moth or, alternatively, long-lasting residual insecticides should be tested. Locating seed production areas away from natural stands may also be a practical approach.

High volume insecticide applications (hydraulic sprays) are generally an effective method for controlling cone and seed insects in southern pine seed orchards. They are expensive, however, and as the trees grow taller, total coverage becomes increasingly difficult. Results of a recent study in Florida have indicated that mistblower insecticide applications under these circumstances are very promising. Seed yield per cone from hydraulically sprayed trees was twice that from unprotected trees, whereas cones sprayed with the mistblower yielded one and one-half times the amount of seed as did unsprayed cones. However, the cost per tree for applying insecticides by mistblower was only half the cost of the hydraulic spray application, and taller trees could be adequately covered by the mistblower.

Newer insecticides now under study will very likely replace the relatively hazardous benzene hexachloride and Guthion currently recommended for cone insect control in the Southeast. Results of continuing tests to find less hazardous insecticides have already uncovered two, the systemics Dimethoate and Shell SD-8447, which give good control of two of the most important cone and seed destroying insects. Further research on these is underway.

Planting survival on cutover pine land in the Southeast is seriously reduced by feeding of weevils on recently planted trees. Millions of seedlings are killed annually by the pales weevil, one of the most important of this group of insect pests. Studies of methods of protecting seedlings have shown that dipping them in 5 percent DDT emulsion prior to planting provides protection equal to that of the previously recommended 2 percent aldrin. DDT can therefore be substituted where danger of aldrin toxicity to mammals or birds may be a limiting factor.

Young hardwood trees may be seriously damaged by tip borers, trunk and branch borers, and defoliators which cause trunk forking and malformation, and reduce height growth. Studies on the prevention of such damage in young cottonwoods by use of systemic insecticides have shown considerable promise. The systemic insecticide phorate, applied to cuttings at time of planting, has protected the cuttings against the cottonwood twig borer, clearwing borers, leaf beetles, leafhoppers and mites throughout the first growing season. Side dressings of phorate applied to the soil between tree rows have provided protection during the second and third seasons. At seven years of age stands treated during their first three years contain about 5 cords of pulpwood per acre more than untreated trees on the same site. This is mostly due to the superior form and freedom from forking and crook in the protected trees.

Following up on work reported in 1965, a helicopter application of Malathion was tested for control of the Saratoga spittlebug in Michigan. Red pine plantings were sprayed with malathion at both conventional and low-volume dosages. The low-volume treatment and a one-pound per gallon per acre dosage both gave good (99.5 to 99.8 percent) population reductions.

Increased interest in the gum forests of the Gulf Coast lowlands of Louisiana and Alabama has revived concern about the continuing annual defoliation of sweetgum and swamp tupelo. Recent studies have shown that the responsible insect, the forest tent caterpillar, can be controlled by aerial spraying with as little as one quarter pound of DDT per gallon of fuel oil per acre. However, this is still considered a hazard to fish and wildlife in these river bottom forests, and chemicals with fewer undesirable side effects are being sought.

Studies in Spain (PL-480) have shown that adults of Melanophila picta, an important flatheaded-borer pest of poplar, can be controlled with dieldrin or Guthion applied to the lower part of the trunk of the trees.

3. Other Control Methods - Male sterilization, tree resistance, site and stand manipulation, attractants

Control methods in addition to chemical and biological measures are also available. Control through stand manipulation has long been practiced in some areas and against some pests, and still holds promise in others. Tree resistance is another approach that will become increasingly useful as management becomes more intensive and additional knowledge is gained about the operations of the resistance mechanisms. Currently there is much interest in the sterile male technique, which uses the insects themselves to effect their own destruction. Sterilization is attempted either through the use of ionizing radiation or chemicals. Coupled with all these, as well as with chemical and biological control, is the rapidly developing field of sex attractants. These materials, known technically as "pheromones", attract insects of one sex to the other. If these can be chemically identified and then synthesized, they could be used to lure insects into places where they could do no damage or could be readily disposed of.

The effectiveness of the sterile-male release technique for the control of an insect depends on the success of the sterilizing treatment and the extent to which the sterilized males are competitive with wild untreated males under natural conditions. This means that the sterilization must be accomplished without physical or physiological injury to the males which would reduce their mating success. It has been generally shown that the susceptibility of germ material to alteration or mutagenesis is at a maximum during the meiosis-spermatogenesis germ developmental stages. Thus lighter dosages of mutagens at this time should result in the desired rate of dominant lethals and/or sperm destruction with fewer accompanying changes in other tissues. In studies on the gypsy moth it was found that although the germ cells are more susceptible to irradiation damage in the larval period during spermatogenesis, other tissue cells of the larva are also more susceptible to damage. Adults resulting from treated larvae were either not sterile or were so crippled as to be ineffective. Gamma radiation treatments must be directed to the pupae, therefore, in which stage the somatic tissues are much more resistant to radiation injury.

Chemical treatment of males is another approach to achieving sterilization. Study of the spruce budworm has led to discovery of effective dosages for two chemosterilants, tepa and metepa, for male pupae of the insect. Emphasis will be placed on these compounds in future studies to develop chemosterilization as a technique to control this important forest defoliator.

Three chemosterilants were evaluated against the locust borer in Ohio by treating each sex separately and then mating them with untreated beetles. This was carried out in series of 20 for each material and a control series. The chemosterilants used were metepa, another similar aziridinyl compound, and hempa, a different type

of material. Hempa was the most effective. When males were treated and mated to untreated females there was an 87 percent reduction of progeny in comparison with the untreated controls. An outdoor cage test using metepa did not produce a significant reduction in egg-laying potential.

A technique was developed that has yielded three generations a year of the locust borer when fed a synthetic diet. The minimum time for development from egg to diet reared adult is 64 days; however, the average developmental period of reared individuals requires 114 days. This technique will permit an accelerated research program in laboratory screening tests of locust borer chemosterilants and studies of host attraction.

The carpenterworm is one of the principal insects causing degrade of hardwood lumber in the South. Laboratory studies in 1965 demonstrated that male carpenterworm moths could be sterilized by direct applications of tepa and that the eggs of females mated to sterile males failed to hatch. These studies indicate that control based on releasing chemically sterilized males in the forest to reduce populations may be feasible.

Two grant-supported studies at the Washington State University are aimed at methods of mass-rearing and sterilizing the European pine shoot moth. Good progress was made during 1965 on both aspects of the work; however, one of the remaining stumbling blocks involves inducing mating. Efforts so far result in something less than 50 percent success, which is not considered satisfactory. The solution to this is under intensive study by both Forest Service and university researchers.

4. Biology and Ecology

a. Bark beetles. The western pine beetle is a major pest of ponderosa pine. The causes of resistance or susceptibility of the tree to the beetle have received considerable attention on the assumption that their recognition would be a major step toward breeding strains of trees that would have resistant characteristics. Recent studies at Berkeley have demonstrated significant differences among the various monoterpene constituents of ponderosa pine xylem resin; limonene and 3-carene were found to be significantly more toxic to the beetles than a-pinene, b-pinene, or myrcene. These results together with findings of wide variations in the monoterpene composition of ponderosa pine resin suggest the involvement of resin quality in intraspecific resistance. If this can be firmly established, within-species selection can be used in the breeding to increase resistance to the beetle.

In other efforts to determine the association of the properties of resin with the resistance or susceptibility of pines to bark beetles, analyses of the fresh pitch tubes and xylem resin of a series of trees were compared, and a set of correction factors was developed to permit the pitch tube analyses to be converted to the resin analyses. Using these conversion factors, the monoterpene composition of 88 fatally attacked pines was determined and compared with that of 202 unattacked trees in the same forest area; the unattacked trees were generally higher in limonene plus myrcene. These results show that pitch tubes can be used to make a post-attack determination of the monoterpene composition of ponderosa pine xylem resin, and indicate that within-species differences in resin quality might be a substantial factor in resistance.

Bark beetles concentrate their attacks by homing in on odors eminating from freshly attacked trees. This has long been considered to have important possibilities, as the attractant character of freshly attacked trees might be used to lure

beetles to their death, without injury to living trees or to beneficial insects. How the flying beetles respond to the attractant then becomes an important question also. Do they all home in on the scent the moment they contact it? Or do some of them continue to disperse before they become responsive to it? These questions have been examined in both field and laboratory experiments in California, and results suggest that the response of beetles to an attractant may be changed from one of dispersal to one of attraction by increasing concentration of the attractive sources. When attractants now being developed are used in the control of bark beetles, these considerations will find application in answering questions such as: How large shall the control area be? How shall the attractant be deployed? How much should be used and in how many centers?

In studies in Idaho the identity of Douglas fir resin constituents was determined using gas chromatographic techniques. Seven monoterpenes were found, including alpha-pinene, camphene, beta-pinene, myrcene, 3-carene, and limonene. Of these, alpha-pinene was the most abundant. Two of the monoterpenes, 3-carene, and an unknown were less concentrated in trees that had resisted attack by the Douglas-fir beetle, implying that these materials may have a role in initial attraction of the beetles to the trees that become infested.

In five-year-old studies on strains of black locust resistant to locust borer, more variation in resistance between sites has been found than between different clones of resistant trees on the same site. Since the first real evaluation of results will be a post harvest in ten years, the present trends are only indications and cannot be considered conclusive.

Tree resistance studies in the Lake States have shown that Scotch pines collected from Eurasia as seeds and outplanted in Michigan are attacked with differing intensities by the European pine sawfly. The least susceptible varieties come from the Ural Mountains; these are consistently under-attacked for their height compared to other races. When pollen becomes available studies will be undertaken to further develop these resistant strains.

One approach to controlling the red pine cone beetle is through the use of prescribed burning. Adult red pine cone beetles hibernate on the forest floor inside buds and tips that break off when the beetles enter them in late summer after having developed in the cones. This makes the beetle population vulnerable to fire treatment during the hibernation period. Studies in the Chippewa National Forest indicated that light burning is completely effective in destroying red pine cone beetle broods. A larger scale test of this method of control is planned over entire seed production areas.

Scientists at Stanford Research Institute and the University of California, working under a contract and a grant from the Forest Service respectively, have synthesized a sex attractant of Ips confusus. This is the first time that this has been done with a bark beetle and it may well open the door for similar breakthroughs with other bark beetles. Materials of this kind may lead to refinements in methods of bark beetle control that will reduce or in some instances even eliminate the need for insecticides.

Information is being developed in the Central Rocky Mountains on different aspects of attraction of trees to the Black Hills beetle. Beetles are attracted through the use of infested bolts hung onto green trees. Attacks continued for as long as 33 days in 1963 with the mass-attack phase taking 12 days. Most of the attacks took place during the evening hours from 4:00 PM to 6:00 PM.

Studies of the seasonal behavior of the southern pine beetle under limited outbreak conditions in Louisiana have shown that attack zones and brood survival vary greatly seasonally, and that these seasonal trends closely parallel those occurring in the east Texas epidemic area. During the cooler months, from November to February, beetle attacks typically shift upwards on the stem and rarely occur in the basal 10 feet. But with the arrival of spring, the attack zone spreads downwards so that most of the bole becomes infested. This extensive area of attack is tied in closely with a significant increase in brood survival, sometimes to the extent of a "population explosion". The implications of this are important from the standpoint of controlling the insect in Texas and Louisiana. Because of explosive populations early in the growing season and the prevalence of natural enemies later on, justification for control from spring to fall may be questionable. Under epidemic conditions especially, every effort should be made to control the insect between October and March.

Southern pine beetle epidemic areas in east Texas and south central Louisiana are characterized by flat, poorly-drained soils with scattered island-like hummocks known locally as "pimple mounds." Initial spot infestations of the beetle have been found to occur much more frequently on flats than on the mounds and the reason for this is being investigated. A study of the soil moisture regime under 40-year-old loblolly pine has demonstrated a relatively fast rise and long duration of a high water table on flats as compared to pimple mounds. In December 1964, for example, water rose under flats to within 3 feet of the soil surface and so remained until the second week of the following April. Water under the mounds did not rise until February 1965 and was below 3 feet by the middle of March. This severe moisture condition on the flat sites is thought to be significant to poor tree vigor and susceptibility to beetle attack.

Killing of immature ponderosa pines by the mountain pine beetle, Dendroctonus ponderosae (=monticolae) is a rapidly increasing problem in the Pacific Northwest. In 1965, more than 140,000 acres were significantly infested in Oregon and Washington. In many areas the problem appears to be the major obstacle to successful management of young forests 50 to 100 years old. A short-term study begun in 1965, seeks to determine the relationship of stand conditions such as overstocking, stand age, and site quality, to current killing by the insect. Findings to date indicate that on an average site (III or IV), killing by the beetle usually begins at about stand-age 60, and often becomes intense by age 70. Killing occurs at an earlier age on better sites, but less often becomes severe. Conversely, damage is more severe on the poorest sites but usually does not begin until the trees are older. Reducing stand density appears to be the key to the beetle problem. Stands on average sites probably can carry about 125 square feet of basal area during ages 50 to 100 years without serious infestation. Stands on good sites may carry up to 150 feet, but those on poor sites may begin to suffer damage if exceeding more than about 100 feet.

Populations of the Oregon pine ips (Ips pini) frequently are important killers of residual trees in recently thinned ponderosa pine stands in the Pacific Northwest. A 3-year study was begun in 1964 to determine the relative abundance of ips beetles attacking and emerging from thinning slash deposited in different areas, years, and months, and slash of different diameters, shading, and concentration. The findings to date indicate that tree killing by Ips in thinned stands is not strongly related to the time slash is deposited, its physical characteristics, or the number of beetles that breed in it. Attacks on standing trees appear more significantly related to physiological condition of the trees at the time beetles are in flight.

There are few cases in forest entomology in which factors responsible for collapse of an infestation are adequately understood. One of these was recently observed in southern Utah, an instance of delayed emergence of the Douglas-fir beetle and its effect on the infestation. The infestation was terminated when brood remained in the infested trees for two winters, presumably as a result of prolonged sub-normal temperatures, and failed to emerge in 1962.

A recent classification of the genus Dendroctonus considers the Jeffrey pine beetle and Black Hills beetle to be the same species. Distinct physiological differences between the two beetles were observed on the basis of their reaction to the vapors of host and non-host resins and monoterpenes. This suggests the existence of separate taxonomic identities.

b. Defoliators. In southeast Alaska egg surveys made in the fall are used to predict where high populations of the blackheaded budworm and hemlock sawfly will occur the following year. However, no information has been available on overwintering egg mortality which could be very important. A study covering three seasons was conducted to learn about this, and has shown that from 22 to 34 percent of the eggs do not hatch. The major loss of budworm eggs is caused by sliding snow and ice. The loss of sawfly eggs was caused entirely by drying following death of the needles containing the eggs. With this information predictions of outbreaks based on egg counts can now be made with more confidence.

The larch casebearer, an insect of European origin, appeared in Massachusetts in 1886, and has now spread west as far as the Idaho panhandle, northeastern Washington, and northwestern Montana. In 1960 several thousand adults of the parasite Agathis pumila were imported and released in heavily infested larch stands. The parasite was recovered in 1962-63 and it is believed that it is well established and will prove effective in checking the spread of the casebearer. As yet direct control of the casebearer is not practical.

An analysis of spruce budworm infestations occurring in the Rocky Mountains from 1948 until the present time indicates that increases in infested acreage during the period may have been due principally to the "in place" buildup of budworm populations and not to moth flights or the dispersal of young windborne larvae. The net extent of budworm-infested forests increased from 756,000 acres in 1949 to a peak of 4,993,000 acres in 1962. Fifty percent of the total was infested from 1 to 5 years; 5 percent was infested for over 16 years.

The relationship between gypsy moth egg-mass density and subsequent defoliation quantitatively defined is a useful tool in predicting the effects of different population levels and, at times, in deciding if, when, and where to take control action. While a crude estimate of defoliation can be made on the basis of the number of egg masses per acre, a more accurate forecast of defoliation can be made by using both egg-mass density at the start of the current year and the egg-mass density at the start of the preceding year; i.e., the trend in density. Even with this consideration, a particular insect density does not determine a particular defoliation, but rather one of an array of defoliation levels. From a 20-year record of egg-mass counts and defoliation estimates in central New England, a defoliation frequency matrix was derived and tabulated in a form for easy reference. This table provides a useful means of forecasting, within a given risk level, the amount of defoliation to be expected from five classes of egg-mass density per acre and the trend in egg-mass density from the preceding year. The expected outcome is given in four defoliation categories.

At the New Haven laboratory an analysis was performed from life tables of the gypsy moth covering a 7-year period to determine whether some particular age interval was especially critical in determining variation in gypsy moth density from one generation to the next. This resulted in a model that describes annual trend as a function of the environmental variables associated with the mortality-causing factors. Of these factors disease appeared primary in dense populations; not, however, in light ones, where no single factor could be readily singled out.

Surveys continued in India (PL-480) for natural enemies of the gypsy moth. Several promising species (all parasitic wasps) have been discovered during the period that the work has been underway. The life histories and ecological relationships of the more promising of these parasites are now being studied in an attempt to learn if any of them are likely candidates for introduction into the United States.

The elm spanworm is an important defoliator of hardwood forests in the southern Appalachians, and, during the past few years, studies have been undertaken on various aspects of its biology and control. In the course of laboratory rearings of the spanworm an entomogenous fungus, Paecilomyces farinosus, was discovered. This fungus was never found associated with the elm spanworm in the field, and it appears that the fungus does not operate except under very humid conditions; then the larvae become extremely susceptible. Rearing spanworm larvae on artificial media, under conditions where a generally high moisture content prevails, may be difficult because of this disease organism.

c. Seed and cone insects. In the North Central States seed production areas continue to produce crops that are inadequate to meet the planting needs of the National Forests. Losses due to insects contribute significantly to the problem. In samples received in 1965 from 10 of the 18 seed production areas, 83 percent of the cones were damaged by insects--the highest percentage recorded during the past 4 years. Of the insects damaging red pine cones, two species caused the loss of all seed in cones that were infested. These are a cone moth and the red pine cone beetle; together these two species destroyed 51 percent of the cones in the sample lots.

The sugar pine cone beetle has been reported as a serious pest of sugar pine cones, and its actions have, at times, been considered responsible for preventing the production of seeds needed to reestablish sugar pine in cutover areas. A closer examination of such areas has revealed that cone beetles do not maintain heavy populations in such areas because they are killed within the cones as they lie on the ground in full sunlight. This finding indicates that the seriousness of the sugar pine cone beetle has in some instances been overrated.

Biological observations have been conducted on two relatively unknown insects that infest pine shoots; these are a gall sawfly, Pleroneura sp., and a weevil, Conotrachelus carolinensis. The sawfly causes galls to form which, in turn, are fed upon by the weevil. This weakens the infested branches to the point where mechanical breakage occurs. The combination of these two insects is a potential problem in some seed orchards.

Host relationships, life cycles, parasite-host interactions, and other biological data have been determined for most of the weevils of the genus Curculio that attack acorns throughout the United States and a monograph on the genus is being prepared. This information, along with that published on the genus Conotrachelus, will complete the taxonomic and distribution studies on the weevils attacking acorns in the United States and will provide background for further investigations on controlling the weevils that are the most destructive to the acorn crop.

Pollen-feeding xyelid sawflies have been found infesting male flowers of slash and longleaf pines in northern Florida. A field technique for rearing adult sawflies has been developed and biological information gathered on several of the species involved. This basic knowledge is needed to help in evaluating the impact of these insects on production of pine seed.

Further improvement in the artificial diet for Dioryctria abietella was gained through the addition of several carbohydrates which were found in first-year slash pine cones. The addition of these compounds to the diet effectively decreases the time needed for each generation to develop and further appears to act as a feeding stimulant for the early-instar larvae. The success of rearing on this diet was improved still further by surface sterilization of the eggs before rearing is commenced; egg sterilization greatly reduces the abundance of microorganisms which have been found to decrease the survival of the first-and-second-instar larvae.

d. Insect pests of young trees. The European pine shoot moth continues to threaten Pacific Northwest forests and studies aimed at determining the feasibility of eradication using the sterile male technique are continuing. As a part of this effort a method is needed to induce mating of the moth in the laboratory. This has been difficult to attain, but in 1965 20 percent of a small laboratory population were successfully mated. Although improvement is needed in the margin of success, this technique does provide a method of evaluating sterilization treatments as well as providing progeny for continuous laboratory culturing of the moths. It is expected that better mating success will result from studies that are continuing. Other progress in European pine shoot moth studies include confirmation that the females mate only once, more knowledge about the sex attractant produced by the females, as well as detailed information about the moths' flight and emergence habits. All of these foregoing details are important if we are going to be able to evaluate the potential for the sterile male eradication technique. Finally in other research on the European pine shoot moth, it was learned that native parasites are not exerting an important amount of restraint on established populations.

Artificial or semi-artificial diets are generally requisite for producing the large numbers of insects needed for intensive studies in physiology, toxicology, and other research areas. In the Southeast, an artificial diet that was developed for bark beetles has been modified for rearing the pales weevil, an important seedling pest. Larvae hatched in the laboratory have been reared to the pupal stage, and efforts are continuing to improve the usefulness of the diet.

Studies on the biology of the pales weevil have revealed over 12 species of associated nematodes. At least 5 of these are new to science. The effect of these nematodes on the pales weevil are not thoroughly understood; however studies are continuing in an effort to clarify the relationships involved.

A cooperative study with the University of Michigan was aimed at learning to what degree insects attack buds and stems of young sugar maple saplings, and hence threaten normal growth during the critical period of tree form development. The straight growth of saplings is important because it ensures that future boles will be free of form defects. It was found that in the plots studied more than 20 percent of the current leader buds were destroyed by insects. Following such destruction, the affected trees developed forks, crooks, and bushy tops--all form defects. At least three kinds of insects--all moths--were responsible. The value of this study lies in identifying and quantifying an important underlying cause of poor tree form in sugar maple. Previous concern was mainly directed to older trees, but it is now clear that the problem begins much earlier. These results point up an

opportunity for research to considerably improve the quality of sugar maple by devising ways to control or prevent attacks by bud-feeding insects in young trees.

In the Southeast, an adaptation of a technique for forcing pine pollen has been applied to loblolly pine branches for the rearing of the Virginia pine sawfly and the Nantucket pine tip moth. Branches prepared and placed in sterile, distilled water can be kept green for up to six weeks. This is adequate time for rearing the tip moth from the egg or young larvae to the adult. By this method one can rear Virginia pine sawflies from eggs to pupae with two or less transfers to new foliage, transfers being required when all the needles on a given branch have been consumed by the larvae.

In the Southeast information on tip moths has often been confused by the lack of an adequate method for distinguishing the immature stages of the various species. Recent studies have indicated that frontal horn characters of the pupae are reliable criteria for separating two of the most common species, Rhyacionia frustrana, and R. rigidana. Limited observations on R. subtropica indicate that this species also can be separated from the others on the basis of pupal characteristics.

PL-480 studies in Colombia, Brazil, and Uruguay are aimed at evaluating insect and disease resistance of introduced North American forest trees. With respect to insects, variable results are being reported from the different countries. In Brazil and Colombia insects do not appear to be causing a great deal of damage; leaf cutting ants are responsible for some damage to plantations in Brazil while different kinds of moth larvae are causing a few problems in Colombia. In Uruguay the European pine shoot moth appears to be particularly serious and may limit pine plantations in some areas.

Studies were concluded in Taiwan (PL-480) on insect pests of introduced North American forest trees. A Dioryctria tip moth was found to damage pine severely; slash pine was among its favorite hosts. A parasite of the sawfly Neodiprion japonica was studied intensively; it parasitized up to 59 percent of host populations.

e. Miscellaneous insects. The grade loss in sugar maple veneer caused by the cambium miner is estimated to be 35 to 40 percent of the potential value of the crop annually. A cooperative study with the University of Wisconsin confirmed the identity of the cause of the pith flecks in sugar maple and established the life history and movements of the mining larvae. It also showed that the systemic insecticide Bidrin was of value in control. While additional developmental work is required, this may provide a lead toward a practical insecticidal treatment for preventing the downgrading of valuable sugar maple veneer stock.

A study of insect-caused deterioration of windthrown conifers in northern California showed that (1) the principal tree degrade was caused by blue stain fungi introduced by bark beetles and flatheaded borers, (2) roundheaded borers caused the most serious woodboring damage, and (3) smaller trees suffered more degrade than larger. In this study degrade due to insects was not as heavy as had been expected; this was attributed to cool summer weather, low insect populations prior to the wind damage, and dilution of the populations as a result of the overabundance of breeding material. Under different environmental conditions deterioration and subsequent tree killing might have been severe. The studies showed that the potential heavy damage that can be caused by woodboring insects does not always come about. Further studies are needed to more closely define conditions and factors affecting this kind of insect-caused damage.

The Colombian timber beetle infests the trunks of living hardwoods in the Southeast such as red maple, post oak, yellow poplar, and sycamore, degrading the lumber and veneer cut from infested trees. Preliminary studies indicate that there are at least 3 complete annual generations or cycles. The first peak attack period in 1965 occurred in May, and for the most part emerging beetles established galleries in the same tree from which they emerged. Therefore the numbers of infested trees throughout the stand changed little from generation to generation.

A completed PL-480 study in Poland resulted in considerable new knowledge about a needle midge, Thecodiplosis brachynterax. The midge is an important pest of pine plantations in northern Europe, especially on poorer growing sites. Populations can be greatly reduced by application of insecticides.

Results were published on studies of the life history and habits of the pine gall weevil, Podapion gallicola Riley. This insect forms galls on red pine, and in Michigan it was found to have a three year life cycle. Damage appears to be important only in the case of ornamental trees.

When balsam woolly aphids infest the main stems of North American true firs, the trees produce unusually wide annual rings, composed largely of dense reddish wood. A cooperative Forest Service and Oregon State University study has shown that the wood cells from aphid infested trees are abnormal in the following characteristics: (1) the cells are circular rather than rectangler in the cross section, (2) secondary cell walls are abundantly marked with checks, (3) the proportion of summerwood-like tissue is greatly increased, and (4) there is an unusual proliferation of traumatic resin canals. These findings point up the need for (1) fundamental investigations of the physiological effect of the aphid on trees, and (2) of the physical properties of the affected wood.

In the Pacific Northwest a series of tagged-tree plots of subalpine and grand fir is examined each year to determine the severity of balsam woolly aphid populations and damage trends. Tree mortality on subalpine fir plots has dropped off sharply in the last few years, reflecting a decline in aphid populations after most of the larger, more vigorous trees have been killed. The surviving 48 trees are mostly slow growing, over-topped, and on poor sites. These trees, although damaged severely in the initial outbreak, have displayed good recovery since the decline of the aphid population. The grand fir trees have been infested for several years, but there has been no mortality. This reflects the unique ability of grand fir to withstand aphid infestations for long periods without being killed. However the growth patterns and form of the infested trees have been markedly changed, resulting in trees that have little commercial value.

5. Wood Products Insects

Subterranean termites occur throughout the tropical and temperate regions of the world, and they are the primary insect enemy of wood products in the United States. The loss caused here by their damage to buildings alone is estimated at over two hundred million dollars annually. Research at Gulfport laboratory has shown that the chlorinated hydrocarbons (chlordane, aldrin, dieldrin, and heptachlor) give three or more times longer protection against subterranean termites than chemicals formerly used and at much less cost for the chemicals, and they are not harmful to plants. One hundred percent protection has been obtained with water emulsions containing 1 percent chlordane for 17 years, 0.5 percent aldrin and dieldrin for 16 years or 0.5 percent heptachlor for 13 years. It is not known how much longer these treatments will remain effective, but, from the performance of lower dosages, many additional years of protection are expected.

Electrical insulation materials, including lead sheathing in the tropics, are attacked and penetrated by termites. Buried electrical cables are short circuited and burned out from moisture entering the point of penetration. The development of materials for wire insulation, cable sheaths, and cable ducts impervious to attack and penetration by termites would eliminate many of these losses. Since 1955 numerous types of wire insulation materials have been placed in or on the ground and in active colonies of termites in the laboratory to determine their resistance to subterranean termite attack. Some of the materials included were polyvinyl chloride, butyl, rubber, neoprene, polyethylene, and natural rubber. However, so far no insulation material intended for burying in the ground has been found that can be recommended for use without treating the soil around the cable with one of the recommended insecticides.

Woods differ to a high degree in their resistance to termites, and knowledge of their relative position on a "susceptibility curve" is important in connection with wood utilization. Some of this is being investigated in India under terms of a P.L. 480 grant, and results in 1965 showed several Indian woods to be relatively resistant to drywood termites, but none were immune. These resistant woods include species of Cupressus, Hopea, and Lophopetalum. Shorea robusta, considered a durable species performed poorly and was badly damaged.

The sapwood of ash, oak, pecan, walnut, and other ring porous hardwood lumber is highly susceptible to damage by luctus powder-post beetles. In a recent study in Mississippi it was learned that a chemical treatment applied by passing green lumber through a dipping vat for 10 seconds immediately after it comes off the green chain can be used to protect the lumber from lyctus. A similar treatment in which 0.1 percent benzene hexachloride (BHC) was added to stain preventive dip solutions has been recommended for control of ambrosia beetles during the drying period. To make the ambrosia beetle treating solution effective for lyctus control also, the strength of BHC in the solution needs to be increased only 0.25 percent. Thus, two very important economic insects and a stain-causing organism can be controlled with one operation.

6. Survey Techniques

Decisions by wildland managers about applied control of forest insects depend upon a sound biological evaluation of each individual situation. Such an evaluation requires such things as the determination of the amount of current tree killing, the level of the insect population, and the extent to which natural mortality factors are present. These components are then used to predict whether damage in the future is likely to increase or decrease; thus the soundness of an evaluation depends upon how accurately we can estimate each component. In studies in California on the western pine beetle in ponderosa pine, it was found that bark beetle sample units as small as 12 to 16 square inches were as efficient as larger ones in estimating mean densities of insects per square foot. Densities in these studies range from 75 to 650 insects per square foot. At the high densities, greater than 400 per square foot, sampling units as small as 4 square inches were efficient. Analyses of variance of brood density measurements made at intervals during four generations showed significant differences between trees, (three per plot), height of sample zone on the tree, (low, mid, and high), and aspects (for cardinal directions); each factor was significant in one-third of the 22 cases. Actually, these samples per tree taken from only one aspect and ten to fifteen trees per plot will probably provide data of sufficient precision to determine which are the key mortality factors associated with changes in population trends.

In order to properly evaluate the course of an infestation for control decisions, a sampling plan must be reliable, accurate, and informative about the insect population. In Utah, a study was conducted to develop an operational procedure for sampling populations of the mountain pine beetle during the mature larval and pupal stages of the insect. The experimental design tested for variation between sample sizes and shapes, locations on the tree, and tree diameters, as well as testing for the nature of the statistical distribution. The results were a new workable technique, using random sampling of sub-populations within a zone 1 foot on either side of breast height of infested trees.

Also in Utah, a sequential plan was devised to obtain an estimate of the mountain pine beetle population trend at the time of sampling. The main advantage of sequential sampling is the elimination of unnecessary work; for instance previous sampling called for 20 trees to get a reliable estimate, while sampling with the new plan requires as few as 2, and no more than 16 trees, depending on the nature of the infestation.

In the Southeast the use of x-ray techniques has been extended to evaluation of within-bark broods of the southern pine beetle. It was determined that the x-ray techniques speeded up the examination 20 times over the previously used method of dissecting the bark, was about equal in accuracy, and could be done at about 1/4 the cost. This technique will add to the efficiency of southern pine beetle surveys.

It has been suggested for some time that techniques might be developed to detect trees under stress; this might among other things facilitate finding trees infested with bark beetles before they could be detected visually. Early indications from tests in the Black Hills are that emitted temperature differences of more than 2 degrees F. between stressed and healthy trees can be detected during periods of sunlight and normal transpiration. The implications of this are that sensors which can detect temperature differences at this level in the middle infrared wave lengths (4.5-5.5 and 8.0-14.0 microns) may be useful for detection of trees under stress.

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C. FOREST DISEASES

Problem

Diseases occur in all parts of the country irrespective of land ownership, on all forest tree species, hardwoods and conifers alike, on trees of all ages from the seeds themselves to overmature forest veterans, and affect all parts of the tree from the root tip to the terminal bud and from the outer bark to the central pith. Forest plants important to forage, recreational, and watershed values are as subject to attack as those in commercial forests. Tree diseases are caused by biotic agents such as flowering plants, fungi, bacteria, nematodes, and viruses and by abiotic factors such as temperature and moisture extremes, nutritional excesses of deficiencies, and noxious substances in the atmosphere. Working singly or in combination, diseases cause death, loss of growth, deformity, lowered quality, or destruction of wood already formed in forest trees. In total, they cause as much loss in our forests as all other destructive agents combined, including fire, insects, and animals. The impact of diseases on growth is estimated to amount annually to 5 billion cubic feet, including 20 billion board feet of sawtimber. In addition, many disease agents reduce the value of wood products in use by an estimated $300 million per year.

USDA and Cooperative Programs

The Department has a continuing long-term program of basic and applied research directed toward the solution of forest tree disease problems and the development of means for their control. The program is a national responsibility of the Forest Service and is conducted at 8 of the 9 Forest Experiment Stations, the Forest Disease Laboratory at Beltsville, Maryland, and the Forest Products Laboratory. Each of the Stations conducts research on a variety of diseases of especial importance in its geographic area of responsibility and may also have leadership for research on diseases of broader regional impact. For example, the North Central Station has primary responsibility for research on hypoxylon canker of aspen, the Northeastern Station for oak wilt, the Pacific Northwest for Poria root rot of Douglas-fir, Intermountain for breeding western white pine for resistance to white pine blister rust, and the Southeastern Station for research on air pollution as a cause of forest tree diseases.

The Forest Service now devotes 73 professional man-years of effort to research in this area and has general supervision over another 26 man-years of foreign professional effort devoted to 11 PL-480 projects abroad. Over one-half of the Forest Service scientists working on tree diseases are plant or forest pathologists, but to provide the talents required to solve our increasingly complex problems, we now employ biochemists, ecologists, meteorologists, microbiologists, nematologists, physiologists, serologists, and soil scientists.

This research program is carried out in cooperation with other Federal, State, and local public agencies. The Department of Defense and the Department of the Navy both continue to support research on the decay of wood in use; TVA and the University of North Carolina cooperate on studies of the effect of air pollutants on trees. The Georgia Forest Research Council provides financial aid, and several State Forestry agencies provide labor, land, and equipment for research on tree diseases. Cooperative aid programs are financed at the University of Hawaii for the studies of seedling diseases; the University of Colorado for the

genetics of dwarfmistletoes; Pennsylvania State University to determine the effect of microclimate on the life cycle of Fomes annosus; Oregon State University for the study of the spread and intensification of ponderosa pine dwarfmistletoe; the University of Connecticut for determination of bacteria associated with wood decay organisms; the University of Mississippi School of Medicine for the biochemical characterization of the fungus Lenzites saepiaria; and Texas A&M for study of the causes of live oak decline and mortality in east Texas.

Under Public Law 85-934 research grants were made to the Brooklyn Botanic Garden for study of the biological effect of root exudates on soil pathogens, and to the University of Mississippi School of Medicine for enzymic and nutritional studies of Cronartium fusiforme. The previous research grants continue: with the University of Wisconsin for research on the nature of resistance in eastern white pine to infection by the blister rust fungus; with North Carolina State University to work on the biochemistry of wood decay; and to Duke University to work on the aerobiology of the fungi of Piedmont forests.

Under PL 480 authority and funds, research programs supplementing and complementing domestic ones are underway in Italy, Poland, Yugoslavia, India, Taiwan, Brazil, Colombia, and Uruguay. Some of these foreign studies are designed to disclose native pathogens of special potential threat to North American forest tree species.

Industrial forestry organizations are also active in forest disease research and cooperate with the Forest Service by freely exchanging research results, making lands and timber available for study, providing technical consultation, and furnishing labor. Several chemical companies donate their products for experimentation and many provide technical advisory services to our research personnel.

The annual outside expenditures for such cooperation are difficult to determine but are estimated to be equivalent to one-half the manpower devoted to tree disease research by the Forest Service.

Progress--USDA and Cooperative Programs

1. Seed and Seedling Diseases

a. Causal organisms. A destructive fungus, Rosellinia herpotrichioides, hereto-fore unknown in California was found destroying the foliage of Douglas-fir seedlings in the Humboldt Forest nursery. An estimated 5 to 10 percent of the seedlings were killed or culled because of this disease. No estimate of the future importance of this fungus could be made, but the nursery is being kept under observation for possible future outbreaks.

Heavy losses of 1-year-old seedlings and cuttings of flowering dogwood have been reported by the Southern Station. Colletotrichum gloeosporioides was consistently isolated from the diseased plants. Inoculations of small trees in Mississippi resulted in stem cankering and leaf dying.

In Poland, a study of forest tree seed disease organisms continues. Pathogens found on seed were as follows: oak - 7 species; birch - 6 species; pine - 2 species; larch - 3 species. All pathogens were recovered from both surface-sterilized and untreated seed. Cephalothecium roseum was the only pathogen important on all 4 species of tree seed. In addition, numerous non-pathogenic organisms were recovered

from oak and birch seed. Further reductions in germination resulted from mechanical injuries to seed in collection, handling, and storage.

Eighteen pathogens were isolated from damping-off diseased conifers in Taiwan. Among them, species of Pythium, Rhizoctonia, Cylindrocladium, Pellicularia, Fusarium, Alternaria, Diplodia, and Fusidium proved to be the most virulent. One of these, Fusidium coniferarum was described as a new species. Its pathogenicity on slash seedlings in Taiwan makes it of possible importance to this country (PL-480).

b. Phomopsis blight of eastern redcedar. Phomopsis blight, caused by the fungus Phomopsis juniperovora is proving to be the most devastating disease of eastern redcedar seedlings in the United States. Research has found that infected trees do not survive field planting as well as healthy trees so thousands of diseased seedlings are culled annually at the forest nursery to prevent planting losses. In control experiments in Nebraska, mercurial fungicides have been found to control the blight on 1-and-2-year-old seedlings in the forest nursery. The addition of spreader-stickers to the fungicide did not improve the degree of disease control.

c. Nursery soils and chemical controls. A severe chlorosis, involving more than 10 acres of pine seedlings in Louisiana, was shown to be the result of low soil pH and excessive application of phosphate fertilizers. The use of lime and less fertilizer increased the pH so that normal seedlings were produced.

Hydrogen peroxide treatment of seeds of 6 Southwestern wood plant species markedly reduced seed-borne microorganisms and increased germination. For ponderosa pine a 50 percent increase in seed germination was obtained. The tests indicated that the greatest benefit might be derived from the near-complete elimination of contaminating microflora and the subsequent prevention of pre-emergence and post-emergence damping-off.

Through research on soil fumigation and control of root diseases, the California Station has developed a control program which has reduced the annual mortality in sugar pine seedlings from 50 percent to 5 percent or less. Disease control is obtained by treating the soil with a combination of fumigants prior to planting.

An investigation of 6 forest-meadow combinations in the Sierra Nevada revealed the presence of Fusarium spp. in the meadow soils and an absence of all Fusaria except F. roseum in the immediately adjacent forest soils. The reasons for the absence of common nursery root disease-producing Fusaria from forest soils are now being investigated.

d. Susceptibility of American trees to foreign pathogens. Several North American conifers have been established in 4 locations in Sao Paulo, Brazil. In 3 of these, the trees are in good condition, but in the 4th, survival is poor and height growth irregular, apparently due in large measure to prolonged drought. No pathogenic fungi have been found although diseases of pines have been reported elsewhere in Brazil (PL-480).

Careful and detailed disease observations are being made on plantations in Colombia. Spindle-shaped swellings on slash pine (Pinus elliottii) are being investigated to see if fusiform rust is present. This disease could seriously restrict the successful establishment of the southern pines in South America. Lophodermium pinastri is present on several pine species but apparently as a secondary organism on adverse

sites. Other pathogens identified in the plantings were Alternaria, Pestalotia, and Fusarium (PL-480).

2. Root Diseases

a. Fomes annosus root rot. The increasing severity of Fomes annosus on conifers in California has led to studies on resistance of conifers to attack. In recent months, this root pathogen has been found attacking and killing 6 previously unreported hosts: Pinus patula, Santa Lucia fir, white leaf manzanita, giant manzanita, incense-cedar, and sagebrush.

A survey of root diseases on Boggs Mountain State Forest in California was made to determine the extent of damage caused by root disease fungi under natural forest conditions. Root diseases caused by Fomes annosus and Armillaria mellea were found in 69 distinct infection centers causing the death of approximately 800 trees. These results emphasize the need for concern over damage by these pathogens in existing natural forest stands, in second-growth forests, and in future plantations in the West.

It is known that Fomes annosus can become established in living trees following infection through wounds. Since the fungus becomes established on freshly exposed surfaces, the question arose in the South that chipping trees for naval stores might be exposing susceptible tissue and increasing infection. No signs of F. annosus infection through chip wounds have been observed after $3\frac{1}{2}$ years of careful surveillance.

Southern pine plantations on sites with high soil organic matter, a high percentage of silt, low pH, and a well defined grass cover have been found to escape damage from Fomes annosus. A formula employing these factors was developed by computer analysis. This formula appears to be a practical means by which forest managers in the South can recognize high-hazard plantations that may require extra care in management.

In Missouri, urea was 100 percent effective in preventing the infection of pine stumps by Fomes annosus. Ammate, ammonium fluoride, and borate compounds were also highly effective. In all cases, stumps were treated with the chemical immediately after trees were cut and were inoculated with a suspension of F. annosus conidia. Ninety-five percent of the control stumps became infected.

In the Southeast, serological comparisons were made among 15 isolates of Fomes annosus from the United States, Japan, India, and New Zealand as one means of testing for possible physiological differences. Results indicated that isolates from the United States were identical. Isolates from New Zealand differed slightly from the United States isolates while the Indian and Japanese isolates were almost identical but differed from both the United States and New Zealand isolates. These results indicate for the first time the possibility of physiological races within Fomes annosus.

Data continue to be taken on survival of seedlings planted in areas so heavily infested with Fomes annosus that the stand was clearcut. Losses during the third growing season in all study plots were less than 1 percent. Some losses occurred in all plots, however, indicating that the fungus is still active after 3 years.

Since F. annosus is capable of initiating new infection centers by colonizing freshly cut pine stumps, considerable emphasis has been given to chemical treatment of stump surface to prevent infection. Three months after treatment in 1962, stumps treated with ammonium fluoride and creosote showed less than 5 percent infection with F. annosus, compared to 100 percent for non-treated stumps. Ten months after treatment, Fomes annosus was present in 8 percent of the roots of stumps treated with fluoride, 45 percent of those treated with creosote, and 75 percent of those untreated. After three years, the fungus was present in over 90 percent of stumps in all treatments. These studies showed that ammonium fluoride and creosote were ineffective in controlling F. annosus, but, more importantly, they emphasized the necessity for long-range evaluation of stump treatments.

To determine the time of year at which colonization of slash pine stumps by F. annosus was greatest in southern Georgia, operational thinnings were conducted at monthly intervals for one year. Inoculation and isolation data obtained during this period indicate that colonization during the spring and summer months (March-September) is decidedly less than during the fall and winter months. Data taken from stump tops and air at stump height indicate that temperatures attained levels of 40° C. (thermal inactivation point of mycelium) or above for sustained periods (1 hour or more) on several consecutive days from April through September. This period coincides generally with the period of low colonization in both inoculated and uninoculated stumps. These studies support previous laboratory findings which indicated potential losses caused by F. annosus could be substantially reduced by thinning during the summer months only.

Data from grant-supported research at Duke on the aerobiology of fungi of Piedmont forests are being analyzed now that methods for collecting spores and relating spore data to weather records have been largely standardized. Intensive 24-hour sampling revealed that the highest spore counts were recorded above the crown canopy. Number of spores decreased to a minimum within the canopy and increased slightly towards ground level. Such studies provide knowledge of the spread and intensification of serious forest pathogens.

The aim of work being conducted by the College of Agriculture in Poznan, Poland, is to study the soil microorganisms on roots and fresh-cut surfaces of stumps and their relation to the root pathogens Fomes annosus and Armillaria mellea. Eleven stands with Picea excelsa and Pinus sylvestris have been selected for study and sampling of organisms has begun. A search for organisms antagonistic to the pathogens, and development of forest management measures to aid disease control are important phases of the project (PL-480).

b. Poria weirii. Exploratory studies in the Pacific Northwest show that Poria weirii, a serious root pathogen of Douglas-fir, cannot use the nitrate form of nitrogen whereas certain soil microorganisms that compete with or inhibit this fungus can thrive on nitrates. These results have led to tests to determine the effect of inorganic nitrate and ammonium fertilizers on survival of P. weirii in forest soil and the possibility of disease control through increased competition from microbial associates.

Research has developed substantial knowledge of the physiology and life history of Poria weirii. The fungus is known to survive best in wood residues buried in soil where conditions limit growth of other soil organisms. Where antagonistic microorganisms are present, however, colonies of P. weirii in buried wood are stimulated

to enclose themselves in zones of dense tissue that possibly serve as defensive barriers against the antagonists.

c. Other root pathogens. A recently discovered root disease caused by Verticicladiella wagnerii attacks pines in western United States. In southern California it has assumed importance as a disease of pinyon pine in the recreational areas of the San Bernardino National Forest and in the White Mountain bristle cone preserve of the Inyo National Forest. It has been found attacking ponderosa pine in several locations in northern California. The pinyon and ponderosa pine isolates were found to be able to attack either host. Soil temperatures above 60^0 F. appear to inhibit infection.

Etiological investigations were begun on an unexplained dying of eastern white pines in Ohio. Mortality commonly occurred in all crown classes and on various exposures and sites. Preliminary findings indicate that trees succumb from a primary root infection which in time results in a girdling of the root crown followed by bole cankering and death of pines. Several fungi have been isolated from diseased trees and are currently being evaluated for their pathogenicity to eastern white pine and related pine species.

d. Soil microbiology. Recent research in the Northwest has revealed a number of little-known organisms that commonly attack the fine-root system of Douglas-fir and other important trees of the area. Among these are aphids, nematodes, and various fungi such as Pythium species. Probably these rarely, if ever, kill trees outright, but their continuing attrition of rootlets can seriously limit a tree's growth and resistance to other damaging agents such as Poria weirii root rot and bark beetle attack.

Tests continue in the Southeast for the evaluation of shortleaf pine seedlings for resistance to infection by Phytophthora cinnamomi. By growing seedlings aseptically in large test tubes, it is possible to demonstrate resistance to root infection in certain controlled-pollination progeny. The method provides a relatively quick test for identifying progeny with the greatest potential for resistance to the littleleaf disease.

Seven hundred progeny from seed produced from 30 controlled pollinations between littleleaf resistant selections have been planted on a 10-acre littleleaf site on the Calhoun Experimental Forest at Union, South Carolina. After one growing season, 99 percent of the seedlings survive.

Methods for the direct recovery of Phytophthora cinnamomi from soil have been worked out at Durham, North Carolina. By the use of a modified Kerr's Pythium medium with mycostatin it was possible to isolate P. cinnamomi without an intermediate apple or potato selective medium. The method was tested in a nursery where 50 percent of the stand of Fraser fir had been killed by the fungus.

Metabolic diffusates of soil bacteria were found to stimulate zoospore formation in Phytophthora cinnamomi. Aseptic zoospores for use in pine culture inoculations with the fungus can now be obtained by the use of suitable barriers that exclude the bacteria but permit the passage of their diffusates.

Attempts to promote oospore formation between self-sterile strains of Phytophthora cinnamomi and compatible isolates through stimulation with extracellular metabolic

diffusates failed. Oospore formation resulted from gametangial fusion rather than from the action of exudates.

e. Mycorrhizae. Work at the Southeastern Station, in cooperation with the New York Botanic Garden, has demonstrated the potential value of several mycorrhizal fungi as the producers of economically useful antibiotics. One fungus has shown marked ability to suppress a bacterium belonging to the staphylococcus group.

Feeding by aphids commonly kills mycorrhizae and rootlets of Douglas-fir and other northwestern conifers. Certain types of mycorrhizae are apparently less subject to attack than others. Excessive damage from root aphids may, therefore, be subject to control through manipulation of the site to favor selected mycorrhizal fungi.

Laboratory experiments at Corvallis, Oregon, have confirmed the root-protecting function of a mycorrhizal fungus. Douglas-fir seedlings on which mycorrhizae were formed with Corticium bicolor suffered no root damage when subsequently inoculated with cultures of a root-killing Pythium species. Seedlings grown under identical circumstances except for omission of the mycorrhizal Corticium suffered loss of about one-third of their root system after inoculation with the Pythium.

Another indication of the protective benefits afforded to tree roots by certain mycorrhizal fungi was noted in studies of root-attacking nematodes. A new species of nematode in the genus Meloidodera was observed infesting mycorrhizae of a 20-inch Douglas-fir in western Oregon. Of the 6 different types of mycorrhizae found on the tree's root system, the nematode was absent on 4, occasional on the 5th, and abundant on the 6th. Apparently the mycorrhizal fungi that produced the first 4 types of mycorrhizae in some way repelled the nematode.

As evidence mounts on the importance of root protection by mycorrhizal fungi, the need for better information on their identity becomes increasingly apparent. Recent studies at Corvallis have indicated a large number of specific tree-fungus associations. Suillus subolivaceous, Hebeloma crustuliniforme, Rhizopogon colossus, and Astreus pteridis have been confirmed as mycorrhizal fungi of Douglas-fir in pure culture experiments.

Thelephora terrestris, a fungus pest in forest tree nurseries, has conclusively been found to form mycorrhizae in the greenhouses at Beltsville, Maryland. This fungus, common in both greenhouses and nurseries, causes losses through heavy growth on stems and needles, which "smothers" seedlings. It is not known to be parasitic. However, the beneficial effects of mycorrhizal formation probably do not compensate for the damage caused by this fungus in the nursery.

That many root-infecting fungi can cause a beneficial increase in the absorbing power of roots is well known but recent studies of their physiology show that these fungi do not all behave in the same way. At Beltsville, the growth of 6 mycorrhizae-forming fungi was studied at 8 different temperatures, ranging from 2^{0} C. to 35^{0} C. Differences were found among the fungi with respect to the optimum temperatures for growth. Respiration rates varied among the fungi with respect to temperatures. These findings should aid prediction of competitive performance in the field, lead to greater successes in isolation of these organisms in cultural work, and perhaps permit manipulation of the environment to favor specific fungi over others.

In a study of mycorrhizal roots of sweetgum at Stoneville, Mississippi, attempts were made to determine by direct isolation some of the fungal associates. Representatives of the Ascomycetes, Basidiomycetes, and Fungi Imperfecti were isolated. No Phycomycetes were isolated, but sporangia and nonseptate mycelium were observed in cross sections of mycorrhizal roots. It appears, therefore, that members of all 4 classes of fungi may form mycorrhizae with sweetgum.

f. Nematodes. Root-knot nematode was found impairing vigor of 23 ponderosa pines in a Southwestern recreational area. This is the first report of a root-knot nematode on ponderosa pine. It is believed that no general or widespread damage will occur, but local damage to high-value trees in high-use areas could be serious. The nematode causing the damage may be a new species.

In a study of saprophytic and other free-living nematodes in marginal ponderosa pine soils in New Mexico, 4 possibly new species of nematodes were recovered. One fungus-feeding nematode has been found capable of limiting growth of Boletus granulatus, a known mycorrhizal fungus.

3. Stem Diseases.

a. Native rusts of conifers. An Intermountain Station study of aecial specimens of Cronartium, the most destructive genus of conifer rust fungi, revealed similarities among the world species that are important to our understanding of potential spread and damage. For example, the recently confirmed fact that the fungus causing white pine blister rust in the Himalayas is distinct from that in North America points to the need to consider great genetic diversity of the pathogen in our white pine breeding programs. Conversely, the close similarity of Philippine and Indian hard pine canker rust fungi to the northern Eurasian species, Cronartium flaccidum, suggests that this is one variable, locally adapted species. Study of world species has helped the understanding and identification of North American pine stem rusts.

Cronartium comandrae is an aggressive killer of lodgepole pine, and a sudden accumulation of damage reports seemed to indicate a recent outbreak that might seriously damage recreational or timber values of this species. The history of comandra rust infection was traced by dating cankers in infested stands from northern Utah to central Montana. Analysis of 730 cankers showed that throughout the region the rust had been endemic for almost 100 years, then increased to epidemic proportions between 1910 and 1945. Infection has again subsided to an endemic level, but older cankers are abundant and are likely to cause increasing damage for a few years, even without new infection. Lodgepole stands should be managed to minimize loss from the old cankers.

The importance of Stellaria jamesiana as principal alternate host for fir broom rust (Melampsorella) in the Great Basin was reported. Widely separated wave years of infection by fir broom rust are recorded from plots in Utah and Idaho: like pine rusts, this disease should be treated as a sporadic rather than continuous damage factor.

Limb rust, caused by Cronartium species, is a slow but destructive killer of ponderosa and Jeffrey pines, especially in recreational areas in both National Forests and National Parks. Chemical therapeutants, although economically promising, have proved biologically ineffective. In larger stems, mycelium was found to grow

within tracheids in the inner sapwood rather than in the bark. It seems probable that present methods of injecting chemicals fail to reach this deep-seated mycelium, and new approaches are necessary.

Rusts affect recreational values of junipers and cypresses in some western areas. Basic studies of several of the causal fungi (genus Gymnosporangium) were made in field, greenhouse, and herbarium. Among the results were revision of the concept of the species (G. clavariiforme) causing witches'-brooms on common juniper; identification of serviceberry as the alternate host in the (Great Basin) of the witches'-broom fungus (G. kernianum) on Utah juniper; a first description of the large, cerebroid galls caused by G. speciosum on alligator juniper; identification of G. cupressi (previously known from Arizona) as the cause of cypress cankers in northern California; identification of G. inconspicuum as the principal cause of the abundant rust on serviceberry fruits (important to wildlife) in the Great Basin; and descriptions of a new species on cypress in California and of one on alligator juniper in the Southwest.

The "two" most abundant pine rust fungi of Mexico, Cronartium conigenum on cones and and Peridermium mexicanum on stems, were found by field and herbarium studies to be the same fungus. Both reach their northern limits in southern Arizona. Outbreaks of the two forms are simultaneous and should be treated as a single problem.

Pine rusts of Baja California were studied for the first time. Limb rust, western gall rust, and coastal gall rust similar to those of southern California were found. Apparently they pose no threat to the United States.

Effects of environment on outbreaks of comandra blister rust were studied in field and laboratory by identifying the weather conditions that favor or prevent the production and germination of pine-infecting basidiospores. Both below-freezing and prolonged high (above 25^{0} C.) temperatures inhibit basidiospore production. No tested basidiospores survived 4 hours of low (25 percent) relative humidity. Basidiospores germinated at 3 to 28^{0} C., with 13 to 23^{0} C. being most favorable. Data of this kind may provide a basis for understanding the long intervals between rust outbreaks and for controlling outbreaks or minimizing their effects.

Derivatives of cycloheximide were tested for their effectiveness to control comandra rust in lodgepole pine. Nine 4-acre plots were selected in an even-aged lodgepole pine stand in southcentral Montana. Treatments were: oil emulsions of semicarbazone and methyl hydrazone derivatives, oil emulsion alone, and unsprayed check. Conclusions after 4 years were that neither of the antibiotics, at the concentrations and rates used, killed the fungus Cronartium comandrae nor controlled the disease.

Eastern and western gall rust distributions were sampled on jack pine in Minnesota, Wisconsin, and Michigan. Western gall rust predominated in the northern areas, and eastern gall rust occurred primarily in the South. Both fungi were found in all three States.

b. White pine blister rust. The Intermountain Station's long-range, applied research study aimed toward providing blister rust resistant F_1 seedlings as seed orchard foundation stock is entering its final phases as perhaps the world's largest and most advanced selection and progeny test program for genetic improvement of forest tree disease resistance. Semi-resistant F_2 stock should be available by 1985.

An evaluation of pollination and seed handling methods used in the rust resistance work has shown, among other things, that the period from pollination of western white pine through conclusive evaluation of the candidate via performance of its progeny--can be reduced to 6 years. Final evaluation of test materials can be made on 4-year-old seedlings inoculated in their second and third season.

A young, 17-acre, grafted experimental orchard on National Forest land near Sandpoint, Idaho, is beginning to produce cones. This planting is expected to supply about 3 million 30 percent resistant F_1 seed for interim planting, beginning about 10 years prior to significant seed production in F_2 orchards of the main orchard program at Moscow.

At Berkeley, California, in vitro tests of fungicides on spores of Cronartium ribicola are underway. These tests should provide the basis for choosing fungicides which warrant screening in the field.

A California field study of chemical control of white pine blister rust on sugar pine is attempting to define safe, effective, economic methods for control. About 50 materials, both antifungal antibiotics and conventional chemical fungicides have been applied in 140 tests on 1,890 diseased sugar pines in natural stands. Both direct and systemic treatments are being evaluated.

Also at Berkeley, electron microscope studies were made of the germinating pine-infecting spore stage of the white pine blister rust fungus. The studies have shown how the spore is attached and the mechanism responsible for forceful discharge of the spore. As a result, a new theory for the mechanism of forceful spore discharge has been described.

Cankered sections from blister rust infected 3-4-year-old western white pine in Idaho were tested for their respiration response to cycloheximide in the effort to differentiate between live and dead mycelia of Cronartium ribicola. There was no apparent effect of cycloheximide on respiration over the exposure interval.

In another attempt to differentiate between live and dead tissues of the rust, a fluorescent antibody technique failed to detect any reaction between fluor plus antiserum and antigen because of a high level of autofluorescence that prevailed throughout the tissues.

Results of a study that may form the basis for making such a differentiation were reported by the Moscow, Idaho, laboratory. The technique involved intracellular localization of individual dehydrogenases in frozen plant tissues. Its further development may allow routine determination of the cytological distribution of these enzymes and should therefore define the living tissues wherein these enzymes are operative.

Grant supported research at the University of Wisconsin has revealed that Cronartium ribicola penetrates the needles of eastern white pine through the stomata rather than through the needle surface as previously reported. Thus it appears that resistance is not due to the leaf cuticle or epidermis acting as a mechanical barrier to infection. Similar work at the Southeastern Station has shown that the fusiforme rust fungus penetrates 1-2-month-old needles directly. These differences in infection methods may indicate inherent differences between the two fungal-host relationships or may reflect needle age differences. Either supposition when proved would have profound importance for progeny testing procedures in the development of rust resistance.

A major investigation of Tuberculina maxima is underway at the Intermountain Station in an effort to determine its real potential for biological control of the white pine blister rust fungus. Studies will be initiated on fungus ecology, nutrition, overwintering ability, and reaction to antibiotics.

c. Fusiform rust. Clarification of the relationship between fusiform rust and eastern gall rust is a critical need in current research on the rust diseases of southern pines. The host ranges and the geographic ranges of both diseases overlap in the Southeast. Fusiform rust, however, is supposedly much more damaging than eastern gall rust. Unfortunately, the fungi causing these rusts are indistinguishable on the oak alternate hosts. In order to put programs of breeding for rust resistance as well as other rust research programs on a sound basis, it must be known specifically what fungus is being dealt with. A Southeastern Station study revealed that on the basis of antigen-antibody tests, spores of fusiform rust and eastern gall rust are distinct. This is the first report of any valid means of differentiating between the spores of these two fungi. Moreover, the globose-shaped galls on loblolly pine produced spores more closely related serologically to typical eastern gall rust spores from Virginia pine than to typical fusiform rust spores on loblolly. This work, therefore, gives valuable leads into the complex relationship between these two rust diseases and their various pine hosts.

There have never been valid estimates made of the distance fusiform rust spores can travel from the oak alternate hosts to cause infection of pines. In the case of white pine blister rust, it is known that the spores usually travel no more than 900 feet, so control measures can be established. The newly discovered secondary sporidia of fusiform rust probably account for the greater distance of disease dissemination for this rust. These secondary sporidia are formed when the original sporidia fall on a substrate not suitable for infection. This study demonstrated that the secondary sporidia are pathogenic to pine, and therefore these spores may serve to increase the longevity and distance of spread of the fungus.

The Southern Station has established a study to determine the effect of temperature on the germination and subsequent development of teliospores, sporidia, aeciospores, and urediospores of Cronartium fusiforme under controlled conditions in the laboratory and to determine the optimum temperature for infection of oak by urediospores and aeciospores.

Detailed environmental analyses have shown a very strong correlation between temperature and relative humidity and infection of pines with fusiform rust. Even with high concentrations of rust spores in the atmosphere, as recorded by spore traps, infection is limited by humidity below 97 percent, temperatures below 59^{0} C., or both. Aeciospores, urediospores, and teliospores require free water for germination.

Oak leaves were found to be susceptible to infection by spores of fusiform rust for only a short period after the leaves emerge. In Mississippi, most infections occur on leaves 6 to 10 days old; leaves 2 to 3 weeks old are resistant to infection.

Lower chain fatty acids inhibited the germination of Cronartium fusiforme aeciospores in chemical inhibition studies in the South. Other compounds such as the by-products of pine or oak metabolism did not reduce germination, or were slightly stimulatory. The antibiotic cycloheximide was a strong inhibitor of germination, but this inhibition was overcome by the pine or oak compounds.

Cronartium fusiforme normally lives only in the tissues of living pine or oak trees. Techniques were developed at the Southern Station by which small pieces of infected pine tissues were grown in flasks in the laboratory. Under these conditions, the rust fungus was still alive after 5 months' incubation though it did not appear to grow.

All 5 spore forms of the fusiform rust fungus are orange colored, because of the presence of the pigment carotene. Carotene is believed to function in energy storage and transfer, but its function in fusiform rust spores is uncertain since we have a strain of fusiform rust with colorless spores. The colorless spores are equally as effective as the orange colored spores in producing infection of pines or oaks.

Several years' observations of a large number of fusiform rust galls in the South revealed that the relationship between pycnial formation and the production of aeciospores does not follow any definite pattern. There are cycles of aeciospore production and inactive stages of the rust in the pines; approximately 68% of the living galls produce aeciospores each year, usually between early March and mid-April.

A new chemical, symmetrical-dichlorotetrafluoroacetone has been reported to be very effective in controlling rust on other plants. However, it proved ineffective against fusiform rust on either pines or oaks in Mississippi.

The genetic composition of the fusiform rust fungus is unknown. Using the white-spored strain of the fungus, the function of the pycnial stage is being studied at Gulfport. Although there is evidence that the rust is heterozygous, a high percentage of the inoculated pines are producing white pycnia, and a genetically pure strain of the rust may be isolated soon.

d. Canker diseases. A survey of 2-to-10-year-old red and jack pine plantations in Upper Michigan and Wisconsin National Forests revealed that Scleroderris cankers are present in about 75 percent of the plantations. Average tree mortality in plantations with infection is about 50 percent. The North Central Station has initiated research on the biology of Scleroderris lagerbergii, the fungal cause of this increasingly serious disease.

More than 20 percent of understory subalpine fir in a Roosevelt National Forest recreation area was attacked by a canker fungus Scleroderris abieticola, previously unreported in Colorado. The number of active cankers appeared to be decreasing. It was suggested that unfavorable weather conditions might encourage new outbreaks and lessen the beauty of the area campsites.

Cytospora canker of Douglas-fir was prevalent on the Pike National Forest in Colorado. Although the diseased trees were generally scattered, it was estimated that some areas had as high as 30 percent of the trees infected and a mortality rate of 10 percent in the seedling and sapling size trees. No practical control measures are known.

Widespread killing of the tops of large sycamores has ruined much good timber in the Mississippi Delta. The affected trees were found to have long, narrow cankers on the main stem. It is now known that these cankers are caused by the fungus Botryodiplodia theobromae. The fungus chiefly attacks trees of low vigor.

Cankers found associated with southern red oaks were common at the waterline on trees subjected to a late spring flood. Fusarium solani was isolated from those cankers and when stems of young Nuttall oak were inoculated with this fungus similar cankers were produced.

A canker disease occurred in Kentucky on European black alders planted on ungraded strip-mine banks ranging in pH from 3.0 to 4.6. Heavy infestations of sooty mold and woolly aphid were omnipresent on all trees. Numerous erumpent cankers were confined to the main bole, but at times pox-like cankers extended onto lateral branches. Two unidentified fungi were isolated from the margins of cankers and are now being tested for pathogenicity to alder.

The basal canker disease of eastern white pine causing serious losses in young plantations in north central New York results from complex interactions between fungi, insects, and environment. Ants, and snow and ice cause necrotic lesions or wounds that frequently become colonized by fungi. Several of these fungi can cause cankers. One has been shown capable of girdling and killing 8-year-old trees in less than a year. Studies are planned to assess tree mortality effects on stand structure and per acre volume of wood.

Data accumulated by the North Central Station suggest a possible genetic variation within the Hypoxylon pruinatum population. Samples from widely separated areas are being compared in vivo and vitro in an effort to determine if differences do exist. Such information would be important in developing aspen resistant to this disease.

In studies of the biology of Hypoxylon, ascospore inoculations on wounded and unwounded aspen seedlings in the greenhouse failed. Field inoculations of various aged aspens were successful when the mycelial inoculum was grown in a grain medium but not when grown on agar medias. Investigations of the mode of fungus transmission and establishment will be expanded.

Under the terms of a contract with the Northeastern Station, evaluations were made of plantings of Asiatic chestnut selections and Asiatic-American hybrid chestnuts. The studies emphasized the importance of site conditions, particularly water relationships in establishing and maintaining plantings. Individual strains showed marked variation in resistance to cold and to the chestnut blight fungus.

e. Dwarfmistletoes. A recently completed study of the effect of Arceuthobium campylopodum in ponderosa pine forests in Oregon indicates that infection reduces growth rates and increased mortality rates. The losses are roughly proportional to intensity of infection and are greater than would be expected from the parasite's effect on crown condition as rated by Keen's system of pine classification.

The Douglas-fir dwarfmistletoe was reported for the first time in Nevada and Wyoming. The parasite seems to be very rare in Nevada but is apparently a serious forest disease agent in local areas in extreme western Wyoming.

Two dwarfmistletoes, Arceuthobium americanum (on Pinus contorta) and A. vaginatum f. cryptopodum (on P. ponderosa) were studied in one locality in Colorado. Over 90 percent of the seeds that landed on the trees were first intercepted by the needles, the remainder on twigs. About 40 percent of the total number of seeds produced were intercepted by the trees. Rain was a major factor in movement of seeds from needles to twigs (where infection takes place). In May of the year following seed dispersal, 14 percent of A. americanum and 6 percent of A. vaginatum seeds produced had germinated on twigs.

The principal dwarfmistletoe on bristlecone pine in the Rocky Mountains was found to be Arceuthobium campylopodum f. cyanocarpum. Two other dwarfmistletoes, A. americanum (principal host, lodgepole pine) and A. vaginatum subsp. cryptopodum (principal host, ponderosa pine), are recorded for the first time on bristlecone pine. Infected bristlecone pines should not be left in harvested areas as they can pass on infection to lodgepole or ponderosa pines.

As part of a continuing study of the taxonomy, hosts, and distribution of Arceuthobium, investigations were extended into Mexico because (1) several species are common to both the United States and Mexico, and (2) Mexico seems to be the area of origin and maximum development of the genus. The studies in Mexico were conducted in cooperation with the Instituto Nacional de Investigacione Forestales of Mexico City. Thirteen dwarfmistletoes were found in Mexico, 5 of which also occur in the southwestern United States. Three new species (A. globosum, A. strictum, A. rubrum) and two new subspecies (A. gillii subsp. nigrum and A. vaginatum subsp. durangense) were described. At least 19 species of pines as well as Abies and Pseudotsuga are attacked. Although the dwarfmistletoes cause serious damage to certain hosts in some localities in Mexico, in general their importance seems to be less than in the western United States.

The dwarfmistletoes have a unique seed dispersal mechanism in which the seeds are forcibly ejected for 30 to 50 feet. In Rocky Mountain studies on dwarfmistletoe seed dispersal and spread, initial seed velocities were measured by high-speed photography. Arceuthobium douglasii and A. campylopodum f. cyanocarpum averaged 2,200 cm./sec. (72 ft./sec.), significantly lower than the 2,600 cm./sec. (86 ft./sec.) average for A. vaginatum f. cryptopodum and A. americanum. The results suggest that the larger dwarfmistletoes have higher velocities. This, in turn, results in greater seed flight distances and faster rates of spread.

Valuable new information for the taxonomic revision of the genus Arceuthobium was procured in the Southwest, southern California, and Baja California, Mexico. The pinyon dwarfmistletoe, A. campylopodum f. divaricatum, was found on Pinus quadrifolia in the Sierra Juarez, Baja California. This species has not been previously known from Mexico or on this host. In southern California, hosts of A. campylopodum f. campylopodum were found to be Pinus ponderosa, P. jeffreyi, P. attenuata, and P. coulteri.

The age of dwarfmistletoe on red fir in California can be determined rapidly and reliably by counting the number of annual rings showing swelling at the infection site and then adding 1 year for the lag period between infection and swelling. Knowledge of age will be useful for studies on population dynamics of the parasite in young fir stands.

Information on tree height and age in relation to dwarfmistletoe infection is of use in planning silvicultural control operations. Studies at Berkeley reveal that degree of dwarfmistletoe infection in understory red firs is directly related to tree age and height. Trees less than 20 years of age were found to be essentially mistletoe-free, whereas trees about 50 years old were more than 50 percent infected. Only about 10 percent of understory trees 3 feet or less in height were infected, whereas all understory trees 10 feet or more in height were found to be infected.

Under the short growing season of the Sierra Nevada, both flowering and seed dispersal of Arceuthobium campylopodum occurred earlier in the fall and dispersal

extended for a shorter duration than at lower elevations and along the coast of California. In years of above-normal summer temperatures, flowering and seed dispersal occurred earlier in the season than in years of below normal temperature. Such knowledge will help forest managers plan harvests to avoid infection of the residual trees from current year's seeds.

The first authenticated collection of dwarfmistletoe on foxtail pine was reported for northern California. The mistletoe was identified as Arceuthobium campylopodium f. cyanocarpum.

f. Mistletoes. At Lucknow University in India, studies of the phosphate metabolism of the mistletoe Dendrophthoe falcata, parasitic on quava and mango trees, show that the leaves of mistletoe contain a four-fold higher concentration of acid-soluble phosphate fraction than is present in the leaves of the host plants. This accumulation of phosphorus in leaves of the parasite offers a promising lead toward control by introducing a toxic phosphorus compound which may well interfere with the normal metabolism of the parasite (PL-480).

g. Heartrots. Red rot, caused by Polyporus anceps, has destroyed 15 percent of the gross volume of virgin stands of ponderosa pine on the Navajo Indian Reservation and is the major defect of this species in Arizona and New Mexico. Although the rot was found to be closely related to several of a number of factors studied, tree age was by far the most significant. Bark color on the lower trunk was a better criterion of red rot cull than broad age classes.

In the laboratory at Delaware, Ohio, researchers have studied the relation between oxygen and carbon dioxide concentration and dry weight production of decay fungi in an attempt to determine their effect on rate of decay. Dry weight production for each of 4 decay fungi increased rapidly with an increase in oxygen from 0 to 15 percent. None grew at 0 percent oxygen. Dry weight decreased with an increase in the carbon dioxide concentration up to 30 percent. Samples of these gases from tree trunks are being analyzed to determine the significance of the laboratory results.

Studies of the nature of hydrolytic catalysts involved in cleavage of wood polysaccharides by brown-rot fungi are underway at North Carolina State University through the Forest Service grant program. The production of oxalic acid and the apparent non-production of celluloses by brown-rot fungi has led to the finding that oxalic acid alone causes considerable deterioration of the sweetgum sapwood used in initial tests.

Under this same grant the distribution, chemical form and seasonal fluctuations of nitrogenous compounds in the stems of trees are being determined. A direct correlation between N content and volume of parenchyma cells has been found for sapwood of 16 tree species but there is no correlation for heartwood. The work to date suggests that sapwood acts in storage of nitrogen as well as of starch and lipids, and that there are seasonal variations in the amount of stored nitrogen.

Increased use of articulated rubber-tired skidding tractors for hardwood logging in the North Central States prompted a study to compare their damage to residual trees with that caused by crawler tractors. With log-length loads somewhat greater damage was caused by the rubber-tired tractor, but the extent of damage as measured by subsequent decay was still acceptable, especially when the economic advantages of this tractor were considered.

Analysis of a 10-year study of decay following logging in northern Michigan is incomplete, but it is reported that in about half of the wounded yellow birch and sugar maple dissected, wound-associated defect had not reached the merchantable portions of the tree and so had no effect on log quality or volume and hence, value.

The value of northern hardwoods for high-quality wood products is affected markedly by decay and discoloration. A New Hampshire based study to increase our knowledge of these defects reports that tissues formed after wounding were seldom discolored or decayed. A distinction is made between true heartwood produced through internal physiological change and columns of discolored wood initiated by wounds or other external stimuli.

Branch stubs were found to be the most important infection courts for organisms causing discolorations and decays in sprout red maple in the Northeast. The fungi isolated most frequently were Cytospora decipiens, Phiolophora spp., Trichocladium canadense and Hypoxylon spp. These fungi were closely associated with bacteria.

Preliminary results from a study of the patterns of discoloration and decay in living trees following inoculations with decay fungi revealed that a succession of organisms and organism interactions occurred. The decay fungi invaded only through tissues occupied first by bacteria and non-hymenomycetes. The results give added importance to the early stages of colonization and to the role that pioneering organisms have on the success or failure of later-invading decay fungi.

Study of the decay hazard following the thinning of sweetgum sprout clumps in the South showed that the amount of rot in the live stem was negligible after 10 years.

4. Foliage Diseases

a. Needle casts. Inoculation of ponderosa pine with Lophodermium ponderosae showed that this newly known fungus can attack and kill healthy foliage. Initial fruiting occurred 2 years after inoculation, but observations of natural infections in Colorado revealed that 1-year cycles can also occur.

Hypodermella medusa on ponderosa and lodgepole pines in the Rocky Mountains has been found to be a complex of 4 distinct taxa. Knowledge of the biological differences between these taxa is basic to the development of effective control measures.

The cause of most of the needle cast that has persisted on these species in the Munds Park and Hassayampa Lake areas of Arizona for more than 20 years has been identified as Hypodermella cerina. This fungus appears to be capable of producing prolonged and damaging stand infestation. A smaller portion of the damage is ascribed to Hypodermella medusa, Elytroderma deformans or adverse environment.

b. Needle blights. The fungus Elytroderma deformans is the cause of an important needle blight of ponderosa pine and Jeffrey pine in the West. This disease was reported for the first time on knobcone pine in California.

Large numbers of spores of the brown-spot fungus, Scirrhia acicola are necessary in order to inoculate longleaf pine seedlings to test the effects of fungicides or genetic resistance to this blight. The fungus was grown in various liquid media at Gulfport in an attempt to produce the maximum numbers of spores. Those nutrients favoring mycelial growth induced little spore production.

Attempts to inoculate seedlings have been rather futile; only 3 successful inoculations having been reported in the South in the past 30 years. Recent studies indicate there is a possibility that the disease is a complex caused by the interaction of 2 or more different species of fungi.

Needle blight caused by the fungus Dothistroma pini is severely damaging Austrian and ponderosa pines in windbreak, landscape, and Christmas tree plantings in the central and southern Great Plains. Christmas tree plantings of shore pine in the Pacific Northwest have also been damaged. This fungus is now causing high mortality to Monterey pine in Kenya, Chile, and New Zealand. Recent tests showed that good control can be obtained on Austrian pine in eastern Nebraska with only two applications of 8-8-100 Bordeaux mixture.

Diplodia pinea, the cause of tip blight, was found to be quite serious on several pines of Taiwan, but the imported slash pine appears to be particularly susceptible. This pathogen occurs nearly worldwide, wherever pines grow, including much of the United States. The fungus revealed very high pathogenic potential in sterilized soil but was insignificant in unsterilized soil (PL-480).

Laboratory studies of the physiology of Diplodia pinea were conducted at the National Taiwan University. The optimum temperature for mycelial growth is 28^{0} C. and optimum pH is 5 to 6. Glycerol and galactose are most favorable carbon sources for mycelial growth, while sucrose and arabinose are best for pycnidial formation, however, sporulation did not increase with increasing concentration of sucrose. Light is an indispensable factor for pycnidia-formation. Ultraviolet irradiation also induced sporulation (PL-480).

In Uruguay, Diplodia pinea has been the only known fungus to attack North American pines planted in that country. A rapid and total withering of pines followed by their death within a few days is being investigated in the possibility that a serious but previously unknown root pathogen may be present. To date, low temperatures and drought have been the primary causes of failure in the outplantings (PL-480).

c. Air pollution. The Northeastern Station's Delaware, Ohio, laboratory presents evidence that chlorotic dwarf is caused by the harmful action of atmospheric gases on the foliage of susceptible eastern white pine. This evidence was obtained by controlling the atmosphere around diseased field trees. In specially constructed chambers designed to filter out air pollutants, diseased trees showed marked recovery. No mottling appeared on current needles for 2 years and premature loss of older needles was arrested. In chambers receiving raw air or air containing only particulate matter below 0.3 in diameter, trees continued to show chlorotic dwarf symptoms.

In treating woody plants for susceptibility to air pollutants, it became desirable to produce more than one flush of new growth per year to prolong the test period. Eight weeks' exposure to a temperature of 40^{0} F. and 9 hours of light per day satisfied the cold and light requirements of dormant eastern white pine and induced their renewed growth in the greenhouse.

To test the suitability of eastern white pine as a biological indicator of air pollutants, 288 seedlings were set out in Tennessee where high concentrations of sulfur dioxide occur and then transplanted in Alabama where there are high concentrations of fluorides. Ninety-one seedlings were injured in both Tennessee and

Alabama. Fifteen were tip-burned by sulfur dioxide and unaffected by fluorides. One hundred fifty-six seedlings were tip-burned by fluoride but uninjured by sulfur dioxide. Twenty-six were uninjured in either area. Pollutant susceptible and resistant trees will be tested further to develop a series of variously affected trees that will serve to monitor the air over large areas.

A survey of air pollution damage to eastern white pine in the Asheville, North Carolina, area revealed that no increase in pine injury or increase in sulfation could be attributed solely to a new soft coal burning power plant. The injury produced was believed to be the result of emissions from many industries in the area coupled with stagnant weather conditions.

d. Pine twist rust. The susceptibility of 10 North American species of conifers in Italy to the rust, Melampsora pinitorque, has been confirmed. They are: Pinus banksiana, P. ponderosa, P. contorta, P. resinosa, P. radiata, P. monticola, P. echinata, P. elliottii, Pseudotsuga menziesii, and Larix occidentalis. On Douglas-fir, infection so far has been limited to cotyledons, indicating that older plants are not susceptible.

From this same study, first reports on the infection trials with poplar indicate that at least 5 North American species of poplar are susceptible. This proves that the rust could perpetuate itself if introduced to this continent since a number of suitable alternate hosts would be readily available. Preliminary evidence indicates that fungicidal protection of pine seedlings in nurseries is feasible, but there is no known way to prevent damage in young plantations and natural stands.

e. Miscellaneous foliage diseases. In a published list of new hosts for broom-causing fungi in the Southwest, Microstoma juglandis on Juglans microcarpa and Articularia quercina var. minor on Quercus dunnii were reported for the first time.

The fungus Glomerella cingulata is native to North America and is serious in Taiwan on camphor. Cultural studies of the pathogen indicated that growth was most favored at a temperature of 31° C. with acidity at pH 7. Most carbohydrates promoted mycelial growth, but organic acids proved unfavorable. An increase in both acervuli and conidiospores was brought about by use of diffused light.

5. Systemic Diseases

a. Oak Wilt. Fungus mats formed under the bark of oak wilt killed trees are an important feature in the life cycle of the wilt pathogen. In the first of a series of studies of factors affecting mat production, bolts cut from diseased trees in Pennsylvania and Missouri and piled in Pennsylvania where mat production is relatively abundant have produced a few mats. Similar bolts piled in Missouri where mat production is infrequent have produced no mats. Six months after cutting, the bark on the bolts in Missouri was loose and sloughing off. These bolts will never produce mats. The bark on the bolts in Pennsylvania is still tight and may yet produce additional mats. Air temperature at the storage site in Missouri was higher and relative humidity lower than in Pennsylvania. Competitive sap rot organisms, chiefly Hypoxylon punctulatum, have been more prevalent in the bolts in Missouri than those in Pennsylvania.

The production of a toxin in vitro by the oak wilt fungus and its purification is the aim of research underway at Delaware, Ohio. Apparently the toxin is present in

relatively small amounts, but it has been appreciably purified by 70 percent ethanol precipitation, ether extraction, ion retardation, column separation, and sephadex column fractionation. The oak wilt syndrome could be partially explained by the presence of such a toxin.

The role of the small oak bark beetle Pseudopityophthorus minutissimus in the dissemination of the oak wilt fungus was investigated at Delaware. It was found that beetles carrying the oak wilt fungus emerged from a high percentage of naturally infected oak trees and that a fairly high percentage of the emerging beetles carried the fungus both internally and externally in a viable state. It was also shown that beetles emerging from a given tree may carry both the "A" and "B" compatibility types of the oak wilt fungus.

b. Miscellaneous. As part of the program to determine the occurrence and extent of diseases of field windbreak tree species, a survey of Dutch elm disease in Nebraska was completed in 1965. The causal fungus, Ceratocystis ulmi is spreading rapidly through Nebraska and is destroying large numbers of elms in the countryside and in communities where control programs have not been established.

In southern Mississippi, experiments conclusively proved that dead and dying slash pine trees near power substations were damaged by urea herbicides which apparently entered underground water supplies.

Seedlings of Douglas-fir, grand fir, western larch, western red cedar, and western white pine were grown in controlled environments by Intermountain Station researchers in an effort to see if the growth responses produced might suggest a cause for pole blight of white pine. Environments included 3 soil profiles (top soil, hardpan, and rock) and 2 moisture regimes (adequate and deficient). After 4 growing seasons total root weight was the only significant source of variation in growth of white pine. Of all 5 species, white pine also appeared least efficient in competing for moisture on all soil types and was least able to adapt to soils having inadequate available moisture and low potential for recharge. The resultant imbalance of root-shoot ratios can cause internal physiological stresses during droughty periods which in turn cause deterioration of the root system and consequent decline in tree vigor, both of which usually precede the appearance of pole blight.

6. Decay of Wood and Wood Products

a. Decay of killed timber. An estimated 4.3 billion board feet of Englemann spruce and lodgepole pine sawtimber were killed by the Englemann spruce beetle during a major Colorado epidemic from 1941-1952. Because it was impossible to utilize the material for sawtimber immediately after it was killed, the question arose as to how much would be salvable for pulpwood as time goes on. About 40 percent of the original cubic-foot volume had been lost where trees were dead for 20 years. About one-third of the loss was due to decay in standing trees, two-thirds to windthrow. It is anticipated that windthrow will be a greater factor in the future.

b. Decay of raw products. Water spray storage of green roundwood is receiving increasing attention as a method of reducing insect-and-fungus-caused losses in stockpiled wood raw materials. Because of its ease of use and the reported absence of appreciable fungus or insect attack in field trials, the method has been readily accepted. In Arkansas, for example, after 6 months of storage under water spray, pulp yields were equal to those from fresh wood. Bolts stored dry gave much lower yields after 2-3 months, and unsprayed logs at 6 months were often worthless.

Under water spray storage the normal fungus flora which is excluded by the near oxygen-free conditions is largely replaced by bacteria and actinomycetes. These organisms are apparently responsible for degradation of the wood parenchyma with a consequent great increase in the permeability of the wood. This effect could be of considerable importance when the wood is treated with preservatives, glues, or paints.

Study of the chemistry of water-sprayed wood is underway inasmuch as there appears to be some change in the extractive content and distribution of extractives under water spray storage. Considering the importance of extractives as by-products of the pulping industry, it is important to know what changes are induced by bacteria and actinomycetes and if there is the possibility of manipulation to increase extractive yields.

At the Forest Products Laboratory in Madison, Wisconsin, basic information on the process of wood decay was materially advanced by developing two highly specialized techniques for observing decay microscopically: (1) An immunofluorescence procedure that will show the location of cellulose-destroying enzymes with respect to the position of the mycelium of the decay fungus within individual wood cells, and (2) a method of fluorochrome staining which permits observation of the attacking fungi while in a living condition.

In a study of the microbiology of deterioration in stored pulpwood chips of Northeastern hardwoods, no appreciable variation occurred in specific gravity loss attributable to chip position in the experimental pile. Laboratory trials showed certain fungi and bacteria from these portions were thermophilic, readily accounting for the level of wood destruction at such high temperatures. Certain white-rot fungi were less able than others to develop on media containing phenolic compounds supposedly produced in the course of lignin breakdown.

The extractives of wood were found to variably influence germination of spores of a decay fungus, stimulation or suppression depending on the species of wood. Two of the most significant findings of these studies at Madison were that carbon dioxide may strongly stimulate germination and that the gaseous emanations of certain fungi may have a similar effect.

c. Decay of wood in use. Studies are underway at Gulfport to secure additional information on the serviceability of siding under different conditions, particularly the effect of finishes (water repellents, paint, and stains) on moisture content and the occurrence of decay.

The relative proportions of siding decay attributable to infection during seasoning and infection after installation are to be determined under a new study at Gulfport. Effects of season of the year on development of decay in siding will also be investigated.

The possibility of controlling decay in exterior building parts by applying on-the-job and in-place protective treatments has been the objective of researchers at Madison. After a 5-year exposure, most of the various light-brush, spray, or dip treatments are protecting the joints of field units under test. Units that have failed are largely untreated controls.

At Madison, final observations of exposure tests--97 percent relative humidity room, and outdoors--indicated that the fungus initially implanted on wood did not harm the varnish finish. However, fungus contaminants growing on the varnish surface of panels in the 97 percent relative humidity were able to penetrate the varnish film to the wood. These fungi badly discolored the finish but did not weaken its attachment to the wood.

In an effort to develop techniques for diagnosing decay, a German needle-penetration device for nondestructive internal analysis of poles was tried by the Forest Products Laboratory. The device appeared to give correctly a measure of advanced and, in most cases, intermediate decay. Identification of the causes of decay revealed that the bulk of pole decay in pine, Douglas-fir, and western red-cedar is caused by 8 basidiomycetes.

Basidiomycetes are predominant among the fungi adapted to completely subsist upon wood. The Forest Products Laboratory, Madison, Wisconsin, and the Forest Disease Laboratory, Beltsville, Maryland, have analyzed data accumulated over 30 years that indicate the associations between type of decay, the host species of wood and product, its preservative content, if any, the geographic area where the decayed product was found, and the decay fungus itself. Such knowledge will benefit standardization of fungus tests and permit interpretation and analysis of data from other research studies.

Microscopical analysis of wood in progressive stages of decay provided new information on the decay processes and properties of wood and fungi involved in the deterioration. The action of the cellulolytic enzymes of a white-rot fungus was restricted to cell wall surfaces; those of a brown-rot fungus and the lignin-destroying enzymes of the white-rot fungus were able to penetrate and act within the cell walls. A relationship was suggested between the lignin content of cell wall layers and their resistance to decay.

d. Natural durability of wood. Investigations at the Forest Research Institute in Dehra Dun, India, indicate that of the 13 Indian wood species tested, 7 are about as resistant to decay as black locust and redwood, 2 are quite variable, and 4 are non-durable (PL 480).

Over 36 percent of the volume of standing incense-cedar in California is cull from Polyporus amarus, yet the fungus is not found on any other tree species. To study the fungus-host relationship, growth tests were made of P. amarus in heartwood extract and in a nutrient growth medium to which heartwood extract was added. The study demonstrated the presence of both growth-promoting and growth-inhibiting substances in the extract. The results suggest that a slight shift in the extractive concentration of the heartwood might affect resistance of the incense-cedar to attack by P. amarus.

e. Causal fungi and their identification. Study is underway at Madison to explore the possibility of using metabolic by-products of wood-inhabiting fungi and certain growth differences as a means of rapidly determining the identity of the fungi in culture. The by-products will be determined chromatographically.

Investigations of decay in oak and hickory in Indiana have shown that essentially the same fungi are involved in decay as previously reported from Ohio and Kentucky. The most common species isolated were Polyporus compactus, P. sulphureus, Poria oleraceane, Stereum frustulatum, and Hericium erinaceus.

At the Forest Disease Laboratory, Beltsville, cultures of 371 undetermined Thelephoraceae in the collection were studies macroscopically and microscopically. At present, 107 have been identified by comparison with cultures of known identity. In addition, 3 species and 1 genus new to the Forest Service collection were found and the basidiocarps from which the cultures originated were identified.

A detailed study of 5 species of Vararia has been made correlating data on basidiocarp structures with the cultural characteristics of these species. This work at Beltsville is an effort to determine a natural relationship among the species of Vararia and other groups of the Thelephoraceae.

7. Miscellaneous Disease Studies

The fungus cause of maple bark disease, Cryptostroma corticale, is also a serious human allergy when high concentration of spores are inhaled. Various wood-using industries in the North Central States have been affected, but only papermills which store sugar maple pulpwood for 1 year or longer are experiencing real difficulty. Scheduling of wood use so that pulping occurs prior to sporulation by the fungus should eliminate the problem.

Three new species of wood-inhabiting agarics were fully described in work at the Intermountain Station. The fungi, all in the family Tricholomataceae are Lentinellus montanus, Lentinus ponderosus, and Panus fragilis.

Seventeen species and varieties of Suillus and 2 species of Fuscoboletinus were studied to ascertain their abundance and distribution in northern Idaho and for their pattern of speciation. Four new species and varieties of Suillus were described.

In a survey of epidemic diseases of trees of Taiwan, 20 fungus pathogens were described, 5 of them as new species. None of the pathogens recorded within the past year appear to offer any great potential threat to North American forest tree species (PL-480).

About 22,000 acres of range lands in eastern California were affected by frost injury to bitterbrush. In some areas, the dieback was serious enough to reduce the carrying capacity of the range and in 2 areas it was so severe that the season of use on current range allotments was reduced. This frost-caused dieback should have only slight impact on the future productivity of the range.

A new species of Curvularia was described as C. protuberata. This fungus was commonly isolated from freshly cut pine stumps in the southeastern United States as well as from dead leaves of various plants in the United States and Europe.

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IV. FOREST PRODUCTS AND ENGINEERING RESEARCH

A. FOREST PRODUCTS UTILIZATION RESEARCH

Problem

Timber and timber-based industries are of major economic importance in the National economy of the United States. Approximately 6 percent of the Nation's gross national product (GNP) and employment originate in timber-based economic activities. Timber increases in value nearly 25 times between the stump and the delivery of finished products to final consumers. In the aggregate, $1 out of every $18 of the GNP originates in timber-based activities, and employment attributed to these activities amounts to about 3.3 million people or approximately 1 out of every 20 employed.

In spite of the magnitude of these figures, the forest products industries have not advanced technically as rapidly as have competitive industries. Very few forest products companies are large enough to finance research programs and most wood products come from small mills that rely on the Federal government for research and development assistance they are unable to finance. The value of Federally owned timber is also greatly enhanced by developments beyond the traditional products and processes which create more profitable uses and maintain or increase markets.

USDA and Cooperative Programs

Major objectives of the Department's program of wood utilization research center on increasing the serviceability of timber and wood products, developing new uses and new processes for wood and on improving its quality. Included is research on the intrinsic wood quality of standing timber, log and tree grades, process and treatments by which wood is made serviceable, pulp and paper, chemistry of wood, and wood engineering.

Over the years, a major program of research in forest products has developed at the Forest Products Laboratory in Madison, Wis. A large part of the more basic and complex research is concentrated at this centralized facility where highly specialized research scientists work in relatively narrow project areas to do research in great depth in their various specialties. Some of the world's finest scientists are included on the staff doing research in highly complex areas including chemistry, physics, engineering, and other wood sciences.

Paralleling this effort, individual projects having a grass-roots flavor have been developed under the administrative supervision of the nine Forest Experiment Stations at various locations. Wood scientists and technologists at these field locations are assigned broad general projects at which they work in close cooperation with foresters and technical people in industry to develop, digest, and synthesize information in a form that can be readily accepted and put to use in the wood-using industries. Forest products utilization research responsibilities of each of the nine Experiment Stations and the Institute of Tropical Forestry have been defined in such a way as to complement the Forest Products Laboratory's program of research and, together with it, constitute a more complete national

program. Assignments of projects to Station locations are made on the basis of (1) where the problem exists, (2) where it can be most effectively attacked and solved, and (3) where the greatest opportunities exist for cooperation that may be necessary to solve the problem. In addition to its major mission in the national program each Station is responsible for providing research assistance to industry and others in its territory on regional problems.

All of the forest products utilization research of the Forest Service is mission-oriented in that it has as its ultimate objective the development of wood products, or cost reductions in the manufacture of wood products that will lead to the wise utilization of one of the Nation's most important and one of the few renewable resources.

Development of solutions to both national and regional problems employs cooperation with university and industry research also. Cooperative action over the past year involved 29 colleges and universities, 22 Federal and State government agencies, 28 industry associations or bureaus, 7 private laboratories or professional societies, and over 100 private companies.

Federal scientific effort devoted to forest products research totals approximately 190 professional man-years per year plus an additional 3.6 man-years in grant research with non-Federal agencies.

During the course of the year, research programs were carried on in Peru, Finland, Pakistan, and India under Public Law 480. Eleven projects involving approximately 36 professional man-years per year are presently underway.

Progress--USDA and Cooperative Programs

1. Wood as an Engineering Material

a. Nondestructive testing of wood. Nondestructive testing of materials that are metallic, homogeneous, and isotropic has attained an advanced state of development. However, in the realm of wood and wood-based products, nondestructive testing is in its infancy, but there is a real hope for the future through the adoption or modification of approaches developed for other materials and in the development of new approaches suggested by the nature of wood structure, its properties, and testing requirements. In view of this low state of development, increased emphasis on research in this field is being made. Some progress has already been made with the development of a simple procedure for obtaining stress rating of full-sized light structural members using a simple lightweight stiffness testing machine. A high degree of correlation was found between the modulus of elasticity (stiffness) of 2 by 4 studs and specific gravity. Also, a good degree of correlation between flatwise and edgewise stiffness was found. The machine holds promise of usefulness as a simple and fast means of testing large numbers of similar light structural members at the production site rather than shipping a smaller sample to a testing laboratory. This and past research shows that nondestructive testing has tremendous potential. For example, it has been estimated that with proper development through research, sound methods of evaluating lumber could increase the total amount of usable strength by 20 percent. Based on present production, this would represent a product value of $200 million per year. The value of other wood-base materials susceptible to nondestructive testing would be similarly enhanced.

Meanwhile other research on nondestructive testing developed a simple hand instrument capable of determining on the spot the approximate elastic strength of the wood in the log or tree by establishing the compressive elasticity of an increment (boring) core and evaluating this in terms of the known proportional limits of compression parallel to the grain of the species. The instrument is somewhat like a pair of pliers with an elastic handle incorporating a dial gage, an indexing plate, and a grooved jaw that seats the increment core. Measurement of compression is made with the dial gage based on the predetermined deflection point on the indexing plate.

b. New housing system. Investigations of wood-frame construction resulted in the development of a new house construction technique which combines increased use of low-grade wood, prefinished components, and rapid field assembly methods without much divergence from conventional construction. From 2 by 4's, boards, plywood, and other common building materials, Forest Service research has developed a house construction technique with new and radically different component parts for modern homes. House builders in both rural and urban areas will be especially interested in a roof system utilizing a new type of truss and plastic-covered plywood-lumber roof sheathing, walls with wide-spaced double 2 by 4's, and thermal sound insulation, interior finish of gypsum reinforced with low-grade boards, and combination sheathing and exterior siding that will help lower costs and at the same time improve house quality. Because only materials of conventional type are used, the system should find ready acceptance among builders, code authorities, and building inpsection officials. This concept will also provide an outlet for relatively low-cost and plentiful grades of lumber and yet provide for the construction of high-quality homes using latest advances in technology.

c. Houses can resist hurricanes. Research on hurricane damage to man-made structures over a period of years showed that not all damage can be eliminated, but a very high percentage of damage observed in the past could have been avoided with simple, inexpensive commonsense principles applied to building construction. The research showed that one of the many advantages of wood-frame construction is its ability to absorb shock and impact forces without failure. This capacity is twofold. First, the wood itself is resilient and can deflect under load. Secondly, the assembly of components with nails, metal straps, lag screws, and similar mechanical fasteners provides rigidity and strength but with some minute movement at the joints, which further absorbs shocks. Thus, a wood-frame structure that has been well designed and constructed of proper materials which have been fastened together with good standard nailing practice and supplemental reinforcing has the capacity to resist hurricane and earthquake forces. The study results were further substantiated by observations of Hurricane Betsy's destruction in Florida and and Louisiana in September 1965.

d. Wood-stringer bridges. Results of both laboratory-controlled and field-loading studies of typical forest-road bridges and full-size model bridge decks indicated that the present American Association of State Highway Officials' design stress criteria are overconservative for maximum stringer shear, but adequate for bending moment. This has led to a recommendation to the American Association of State Highway Officials that design stress criteria for maximum stringer shear in its Specification for Highway Bridges be modified. This means that for maximum efficiency and economy interior stringer sizes may be reduced. The study further showed no need to change existing design criteria for outside stringers.

e. Corrugated containers--wet, strong, and rigid. A major breakthrough has resulted in the development of corrugated fiberboard containers that will maintain strength and stiffness under wet service conditions. Treatment of fiberboard components with a low-molecular-weight, water-soluble phenolic resin on a commercial manufacturing basis improved the containers to the extent that they retained about 74 percent of their dry strength in highly humid atmospheres and about 41 percent after 24 hours' soaking in water as contrasted with 47 percent and 8 percent strength retention respectively for untreated containers. Thus, containers can be made that will meet the demanding requirements for overseas shipments of military supplies and can provide for safe shipment of fresh or frozen agricultural products. While further developments to improve performance of these containers are anticipated, the container fiberboard industry is cooperating in studies to make this product a marketing reality.

2. Timber Quality Characterization

a. Wood quality and density relationships. Producers of structural lumber, plywood, laminated arches and beams, and high-quality transmission poles and piling are concerned with the density of their raw material. Their interest, of course, stems from the well-established relationship between specific gravity and the strength and stiffness properties of solid wood and laminated products. Because their product is judged on the performance of individual pieces, knowledge of the variation in specific gravity among trees and within individual trees will be useful to them in producing high quality products.

Wood density has been used to obtain better information on the quality of nine western species (Western Wood Density Survey). Data on specific gravity distribution from Forest Survey data, together with known mechanical property-specific gravity relationships, resulted in improved estimates of average structural properties. The heterogeneity in properties over a species range has been described by a method of analysis involving estimates of mean properties for unit areas. Together with the variability index, this technique permits the grouping of species or the grouping of areas for marketing purposes. It is therefore possible for industry to establish efficient and economic marketing groups with assurance that each segment of the group has received full consideration in development of design stresses and with equal assurance to the user that the product will meet imposed structural demands. Meanwhile, a "Southern Wood Density Survey" has furnished the pulp and paper industry with information on major differences in specific gravity between species. Application of the density survey data will make possible the estimating of average pulp yields by species and diameter classes for various areas in the South.

b. Determining multiproduct potential in standing timber. Usual forest inventory methods are designed to estimate the potential yield of a single primary product (e.g., lumber). They commonly are based on subjective judgments and perhaps biased estimates. If there is a need to estimate stand potential for some other product (e.g., poles, pulpwood, or veneer) the original data cannot be used, and it may require spending additional funds and manpower for a reinventory which, in turn, may have limited usefulness. A promising inventory technique based on stand and tree characteristics for determining suitability and potential yields for multiproducts has been developed. Subjective judgments and estimates by field men are eliminated or minimized. Data on basic tree characteristics can be reanalyzed to meet any one of several inventory needs.

This type of multiproduct inventory will save resource management agencies tremendous amounts of money and manpower by (1) making maximum use of a single set of data and (2) eliminating the need for reinventories of the same geographic area. Such flexibility will improve the manager's ability to plan and manage which will become increasingly important as management and utilization intensifies through time.

c. Evaluating timber quality. Timber quality can be evaluated either (1) directly by measuring properties and characteristics of a unit of raw material, or (2) indirectly by recording the mix of products resulting when timber is processed in a specified manner. Concept (2) implies a different evaluation for alternative processes, but also it leads to consideration of tree quality in a series of successive evaluations (through series of production operations), ending with quality ratings of the final product.

Analysis of directly measured data may be simpler than analysis of indirectly measured data through new statistical procedures. Multivariate regression provides a technique for predicting the output of several products from a single unit (tree, log, bolt, etc.), and for making statments about the accuracy of predictions. It also gives a basis for extending timber quality investigations to analysis of variable production processes. This type of model development is important because of its promising research implications and its potential for improving industrial practices through better understanding of basic conversion processes.

3. Pulp and Paper Products and Processes

a. High yield pulping process reduces pollution. Earlier research has shown that kraft-type pulp yields can be raised as much as 25 percent by the addition of polysulfide to the kraft liquor. This causes less wood to be lost in the spent pulping liquor and thereby helps reduce water pollution. Meantime the economic attractiveness of the high-yielding polysulfide pulping process has been enhanced by the discovery of a new recovery process that facilitates reuse of the chemicals in the sulfur-enriched polysulfide pulping liquor. In addition to cost reduction, the recovery process also helps to reduce air pollution. Essentially, this process consists of recapturing hydrogen sulfide generated in the digester during pulping, and of reconversion of the spent liquor by evaporation, oxidization to sodium sulfate, and reduction to sodium sulfide. This research showed that rate of removal of hydrogen sulfide from black (spent) liquor by stripping was found to be increased at higher temperatures, by controlling the pH between 10.7 and 11 with addition of carbon dioxide, and by adding nitrogen to the steam during stripping to act as a carrier of gas. The more efficient stripping not only reduces recovery process time but makes smaller and less costly recovery equipment feasible.

b. Pulpwood chip storage. Production of pulp chips from plant byproducts at sawmills, veneer mills, and other wood-using plants has increased rapidly in recent years and in 1963 amounted to about 11 million cords, some 24 percent of all pulpwood consumed at U.S. mills in that year. The economic advantages in the transport, storage, and handling of chips in comparison to roundwood will increase the attractiveness of wood chips as a pulp raw material. Savings will be real only if pulp yields and quality are not sacrificed during chip storage. Previous studies on softwood chips show that loss in wood substance during storage and loss in pulp quality due to storage are about the same as for roundwood. In kraft pulping, the use of chip piles appears to present no problem, with the exception of a possible loss in yield of tall oil and turpentine. However, in storage of hardwood chips different reactions have been found.

Research on storage of hardwood chips showed that the reactions in a maple, birch, and beech outside chip pile differ from those in roundwood storage since heating occurs. The rise in temperature is great enough to inhibit the development of the true wood rot fungi in certain portions of the pile. There is a wide temperature range from the exterior to the interior of the pile, so that a wide variety of micro-organisms are encountered. In the cooler portions of the pile, the usual wood rots find satisfactory growth conditions. In the warmer sections of the pile, the usual wood decay fungi are replaced by thermophilic organisms not normally encountered in roundwood decay.

Loss in wood substance amounted to about 6 percent in 6 months storage. Losses of wood extractives amounted to 50 percent in 6 months storage. Oxidation of the extractives caused discoloration of the chips and the rapid temperature rise in the chip pile. No change was found in the lignin-carbohydrate ratio of the stored chips.

There was a definite decrease in sulfite pulp yield, as well as a decrease in pulp brightness, so that increased quantities of chlorine were required for bleaching. On the other hand, there was no significant trend noted in the physical properties of the unbleached and bleached pulps due to wood storage.

The most interesting and surprising fact which this study revealed is the rapidity with which these detrimental effects take place. Discoloration of chips and loss of pulp yield and brightness were apparent after only 1 month of storage in the chip pile.

c. Strength properties of paper. Edgewise compressive strength, a basic mechanical property of paper, can be improved without adding fiber or chemicals, experiments with one pulp indicate. Handsheets made of the pulp gained 60 percent in this property, as well as 130 percent in stiffness, when restrained from shrinking during drying. Earlier work had shown that stiffness could be markedly improved in this manner, leading to the supposition that compressive strength might also gain. Much the same kind of restraint can be obtained on the paper machine with strategically placed curved expander rolls and by controlling the orientation of fibers in the paper sheet.

Edgewise compressive strength is of particular importance in papers that will be subject, in use, to loads capable of either tensile or compressive failure; under such conditions failure invariably occurs in compression.

Meanwhile in studies of stiffness, a basically important property for such products as foodboard, cup stock, and linerboard, data on fiber orientation and drying restraint indicated that stiffness can be predicted and design criteria developed for papers of specified stiffness. Formulas for elastic relations of orthotropic laminates available in the literature were found to be usable in the design of paper products. With these formulas it is possible to calculate stiffness of paper at several levels of fiber orientation.

4. Serviceability of Wood Products in Use

a. Improving fire performance. Fire tests in building corridors produced definite evidence that fire spreads inside building by "flashover" of hot combustible gases to fresh oxygen rather than by spread of flame across burning surfaces. This flashover occurred at approximately the same time whether the wall linings were of

combustible or noncombustible material and occurred before any appreciable flame spread along the wall lining.

In other work, fire-retardant-treated wood studs on 16-inch centers in partitions have been tested under ASTM specifications and accepted by the codes for 1-hour fire-resistive nonbearing construction. But 24-inch fire-retardant-treated wood spacing had not been so tested until recently. The new tests showed that fire-retardant pressure-treated wood studs on 24-inch centers in nonbearing partition panels successfully passed the 1-hour fire endurance and the hose-stream tests as specified by the American Society for Testing and Materials.

b. Environmental effects on wood properties. Previous research on evaluation of new products has generally been based on laboratory exposure, followed by several years of actual use in a few locations. These evaluations demonstrated the service life of the product and were used as a basis for developing quality control tests. This procedure is responsible for providing the high-quality wood products we enjoy today. The long-term observation, however, is being challenged in this age of rapidly advancing technology. Therefore, to aid in new research on environmental conditions, instrumented exposure structures were built at two locations, one at Madison, Wisconsin, and one at Athens, Georgia, for the purpose of predicting the service life and performance of new building systems and new products to accurately guide the manufacturer, the consumer, and the insurance and building code authorities.

Other research was successful in developing an equation for predicting maximum surface temperatures of wood. This development will be useful to the wood, paint, and adhesive industries who have long been interested in the temperatures, particularly maximum temperatures, of wood and wood products used outdoors. Extremely high temperatures can affect the durability and life of a product unless it is specially designed to withstand such temperatures. Until actual environmental conditions, such as the daily temperature ranges, could be accurately defined, it was difficult to establish realistic accelerated testing methods for wood siding and sheathing and for finishes and adhesives that must endure weathering. This equation has been shown to be quite accurate for predicting the maximum temperature of various wood products in various exposures.

c. 20 years of research in laminated timbers. The results of early research in laminated timbers have been substantiated by studies of laminated bridge timber performance. The studies show that laminated timbers of Douglas-fir and southern pine glued with resorcinol and phenol-resorcinol adhesives and treated with creosote, creosote-oil mixtures, or pentachlorophenol in heavy oil have given good performance in bridges for periods up to 20 years. The exuded coatings formed by oilborne preservatives minimize checking and delamination, apparently because they retard moisture changes and significantly reduce shrinking and swelling. Bridge stringers glued from creosote-treated southern pine are also in very good condition about 19 years after fabrication.

Studies of waterborne preservative-treated bridge timbers showed that these preservatives do not give the same protection against shrinking and swelling as oilborne ones. Surface checking and delamination are much less apt to develop in laminated timbers treated with oilborne preservatives. No evidence of decay was observed on external faces of timbers treated with either oilborne or waterborne preservatives.

This research shows that laminated timbers can be used with confidence and long term performance can be predicted by a short term test.

5. Solid Wood Products and Processes Development

a. Paneling and flooring from low-grade hardwood logs. From small, low-grade hardwood logs, research has developed a system for producing an experimental wall paneling and flooring. Short cutoffs of the panel material can also be utilized as parquet block flooring. This system uses the concept of going directly from the logs to the products instead of first sawing lumber that must be later re-sawed into the product. The system consists of first sawing low-grade logs on the headsaw to near the thickness of the finished product. Then the thin unedged boards are press-dried. Press drying was accomplished between heated press platens. This method of drying reduces width-shrinkage during drying, and also reduces shrinking and swelling of the finished product by about three-quarters as much as kiln-dried boards. Press drying of oak also produces a color about the shade of chestnut or light walnut and accentuates the character marks. Next, the boards are sized to proper thickness and cut 2, 3, 4, and 6 inches in width and 2, 4, 6, and 8 feet in length. Then by mixing different widths and lengths of boards, packages 6 inches wide and 8 feet long are assembled. Each layer in a package will cover a wall or floor surface 4 feet square and each package of 8 layers will cover a surface 32 square feet. A unique feature is that widths are actual, that is, a 6-inch-wide board will cover a 6-inch-wide floor or wall surface. Therefore, no allowance for shrinkage is necessary as with conventional strip flooring currently on the market. Installation of the side- and end-matched panels is simple, and only a few carpenter's tools are required.

This product can be produced from the forests of the Northwest, North Central, and Appalachian regions where vast quantities of little-used hardwood timber are available. The processing technique developed by this research can eliminate costly steps in production, can utilize local machines and labor and can provide an attractive product from low-quality logs.

b. Ceiling tile with unique acoustical properties. Using pulp chips with a urea resin binder, research developed a ceiling tile with unique acoustical properties. The random alinement of the 5/8-inch-long pulp chips create a rough surface on 2- by 4-foot panels. This surface contributes some sound absorption with a unique flat response regardless of the frequency of the sound waves. In this respect, it differs from many conventional sound-insulating materials, which absorb the higher frequencies more effectively than low frequencies. The board-type ceiling tile is bonded in a typical platen press particle board operation, using a 4 percent urea resin binder. Designed to span supports 2 feet apart, the 2- by 4-foot panels are 3/4-inch thick and made to a density of about 24 pounds per cubic foot. One surface is sanded and painted with a flat, interior paint. Because it retains its rigidity in damp and humid areas, it should be especially suited for below-grade application.

c. Improving southern pine plywood. Research on the interacting effects of seven variables on the properties of exterior plywood made from loblolly pine showed that gluespread could be reduced from 85 to 75 pounds per thousand square feet without reducing the quality of the plywood. Based on current production of southern pine plywood, the industry could save approximately $1 million annually by using less glue. Further research revealed that plywood of maximum wet-shear strength was obtained by: (1) using veneer of high specific gravity; (2) peeling veneer hot and tight; (3) peeling in such a way that lathe checks were shallow; (4) using veneer cut from slow-grown trees; (5) using either no secondary extender

(best) or using wheat flour only; (6) increasing gluespread; and (7) minimizing assembly time. These experiments show that increased durability of plywood in exterior exposure is a characteristic of plywood with high wet-shear strength.

6. Chemistry of Wood

a. Lignin formation. Previous research by the Pioneering Lignin Chemistry Unit demonstrated that free redicals exist in wood preparations and that free radicals can be synthesized by the oxidation of lignin model compounds. This provided experimental support for theoretical postulations that these chemical entities are involved in the formation of lignin through biosynthetic processes in the tree. This work further demonstrated that certain model compounds believed to represent segments of the extremely complex lignin molecule can be converted to relatively stable free radicals by oxidation. Such radicals, possessing an unpaired electron, can be measured with an electron paramagnetic resonance spectrometer. The detailed spectrograms proved to be distinctive for each compound, hence can be used for identification. Such advanced instrumentation is of great importance in studying free radicals and their reactions.

It has long been theorized that lignin biosynthesis in the tree is in some part the result of free radical formation from coniferyl alcohol followed by its polymerization. Coniferyl alcohol is a chemical constituent of the growing portion of a tree.

The stability of free radicals from lignin model compounds offers important support to present theories of lignin biosynthesis.

This work in securing relatively stable free radicals was particularly successful with the family of model compounds known as syringols. These are thought to constitute a major portion of the molecular structure of hardwood lignin. Model compounds related to softwood lignins, the guaiacols, either failed to respond at all or responded too rapidly to provide measurable amounts of free radicals. In nature, free radicals may appear and disappear almost instantaneously in biosynthetic processes. Further research showed that lignin precursors are synthesized by the tree and transported to the cambium where active cell growth is in progress. Here the simple precursors, through the action of appropriate enzymes, are linked together into progressively more complex material until finally the end product, lignin, results.

This research will help in better understanding of the chemical nature of lignin and will permit improved pulping techniques and better solutions to the waste problem, and will enable scientists to design uses for this abundant product of nature.

b. Chemical by-products from wood residues. Research on the use of wood residues in chemical conversion processes is primarily a problem in the utilization of the main constituent, cellulose. Approaching this problem by a saccharification procedure has not been economically successful in this country. The major difficulty can be ascribed to the extreme resistance toward hydrolytic attack exhibited by cellulose, a resistance that stems from the impenetrability of the close-packed, highly ordered crystalline arrangement of the cellulose molecules. It is this resistance that governs the relative rates of sugar production and sugar destruction, which in turn govern the overall yield of sugar. An evaluation of two pretreatments for modifying cellulose fine structure to accomplish a favorable change in the kinetics of the saccharification process showed that while the hydrolysis rate of cellulose was found to be measurably enhanced by such pretreatments, the magnitude of the improvement in sugar yields was of borderline significance.

c. Surface modification of wood. Surface treatment of wood with phenolic resin was shown to furnish a much improved foundation for clear finishes that do not absorb ultraviolet light. Experiments comparing such a finish with one that does absorb ultraviolet convincingly demonstrated the superiority of the nonabsorbent finish.

Improvement in the durability of film-type natural finishes for wood used outdoors, such as house siding and trim, was attained through improvement of the dimensional stability--that is, resistance to swelling and shrinking under wet and dry conditions--of the wood surface as a base for finish, on the assumption that dimensional changes stretch or compress the film of finish.

Past research had shown that phenolic resin impregnation of the cell walls of wood is a highly effective way of dimensionally stabilizing wood. That research, however, had stressed complete impregnation. The new approach undertaken--with the object of lessening treatment costs--was to stabilize only the surface zones of the wood.

Other experiments having shown that polyurethane absorbs ultraviolet at wavelengths of 4,000 Angstrom units or less, it was decided to try a finish that does not absorb ultraviolet. A polyalkyl methacrylate emulsion finish was chosen for this work on phenolic-treated specimens of ponderosa and southern pine with excellent results. After 8 weeks of exposure to the laboratory conditions, no checking was detected in either the finish or the ponderosa pine. On the southern pine specimens slight yellowing was evident at the interface between finish and wood, but the methacrylate did not undergo even microchecking such as had occured in the polyurethane varnish.

7. P. L. 480 Research

a. Finland. Research on factors which influence the impregnability of wood showed that Baltic pine timbers that had been "ponded" or "floated" prior to sawmilling and drying admitted treating solutions more readily than similar "nonponded" timbers. Temperatures at which timber was subsequently dried had little effect on impregnability if the timber had been "ponded," but in "nonponded" specimens those dried at higher temperatures were more difficult to impregnate than those dried at low temperatures. This research was terminated during the reporting period.

Other research in Finland on the chemical behavior of wood cellulose resulted in the discovery of the retention of iron by cellulose and the successful determination of cellulose molecular weight by light scattering in iron-tartaric acid solutions. Since metal contaminants are becoming of increasing importance to pulp and paper users in food packaging, the results of studies on retention of iron by cellulose through X-ray fluorescence techniques are an important contribution to science.

b. India. Investigations involving the planing techniques of Indian timbers indicate that there is apparently a correlation between average hardness of the wood and energy consumption during the process. Linear graphs have been developed based on research data and tentative simple algebraic equations have been established for estimating energy consumption as a function of hardness, depending on grain direction.

Other research in India involving the investigation of phenolic constituents of certain woods and barks of Indian and North American species has isolated two new types of compounds from Dalbergia latifolia, two new leucoanthycyanidins from the genus Quercus, and two new terpenoids have been identified in the bark of the genus Betula. A new species is also under investigation in each of these genera.

c. Peru. Research on the collection and identification of wood and herbarium materials from Peruvian trees showed that nine species and one variety out of 136 trees collected proved to be new to botanical science. Sufficient material from 450 species were sent to the U. S. for exchange purposes and simple wood property tests. Results of this research will help Peru increase the contribution of the timber resource to the country's economy by providing exact botanical identification of local species along with knowledge of potential uses of these species.

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B. FOREST ENGINEERING RESEARCH

Problem

Forestry operations in the United States, and in the world in general, have not kept pace with other basic industries in improving labor output, in mechanization and automation for improved efficiency, and in reducing the physical drudgery involved. Man-strength hand operations still retard realization of an industrial revolution in most woods operations. Mechanization comparable to that achieved in American agriculture is sorely needed.

The forest industries are, historically, decentralized. There are many woodland owners, contract loggers, mill operators, equipment manufacturers, and sales organizations, each concerned with their individual problems. Equipment manufacturers, generally, have done a remarkable job in producing the machinery used in today's operations considering that they have been able to attack only subelements of overall systems without adequate engineering guidance from the purchaser. Neither the purchaser nor the manufacturer has been staffed to analyze the whole problem and specify operational goals.

Small studies to support piecemeal improvements will never lead to the major goals required--giant steps in cost reduction and improvement of forestry operations.

Not only have the forest industries lagged in mechanization and improved efficiency, they are now beset by increasing restrictions due to competing forest interests, such as recreation, water, wildlife, and livestock uses which tend to increase the already high costs. There has been relatively little systematic research of how diverse elements of forestry operations, including harvesting, fit together--or how they affect other values such as soil, water, aesthetics, etc.

The constant price squeeze on wood products in the marketplace requires more efficient bulk collection methods for harvesting and delivery of raw material to processing plants. New systems of logging are needed for harvesting of lower valued timber, for operations in more difficult access areas, and for operations in areas with multiple use contraints.

In the East and South the demand for pulpwood is increasing currently at nearly 11 million cords per year. To meet this increased demand with today's mechanization will require about 56,000 more workers per year in an industry where it is already difficult to obtain labor and maintain current production. Radically improved worker productivity is urgently needed through mechanization and more efficient systems of operation.

In the West conventional logging and road building in steep terrain and on critical soils tend to increase soil erosion, landslides, and flood damage. These operations are frequently incompatible with landscape and recreation values. Over 6.5 million acres of commercial forest land in western Oregon and western Washington cannot be logged under current methods. The annual losses in terms of allowable cut in these currently non-loggable lands are about 840 million board

feet. For each mile of road constructed in the rugged terrain of the Douglas-fir region about 5.5 acres of timberland are taken out of production. A radical reduction in roads required for harvesting is needed to protect land and production values.

Accordingly, research is urgently needed to establish the operational criteria for forestry operations and to develop the concepts required to perform them economically and in accordance with good land usage.

USDA and Cooperative Programs

Five problem areas in United States forestry have been selected for research attack. These problem areas characterize engineering obstacles to, or opportunities for, achievement of forestry and land management objectives in large segments of United States forestry. These areas can best be described as complexes having special problems or opportunities created by interrelated factors such as timber values, markets, accessibility, silvicultural requirements, watershed and recreation needs, current or potential industrialization, degree of mechanization, terrain, and weather. The areas have been selected on the basis of combinations of factors which create a problem or situation.

An engineering research program has been established for each forestry problem complex in the geographical area of the country where the problem is dominant. These programs are located on or close to college or university campuses and operate in close cooperation with the engineering schools and with other disciplines in the institution.

The following problem areas or complexes have been selected:

1. Steep, erosible mountain slopes with small stemmed timber of relatively low value.--The problem is characteristic in the lodgepole pine forests of the Rocky Mountain region of the United States but similar conditions exist elsewhere, particularly in the western United States. The research program is located at Bozeman, Montana, and operates in cooperation with Montana State College.

2. Intensive forest management complex.--The problem is characteristic of forests in the South and involves mechanization of the "timber factory" production from "pollen to product," reduction of excessive hand labor in current methods to meet requirements of an ever-diminishing labor supply for forest work. The research program is located at Auburn, Alabama, and operates in cooperation with Auburn University.

3. Deteriorated northern hardwood stands.--The problem is characteristic in the hardwood forests of the Great Lakes area, but similar conditions exist in the Northeast and to a limited extent in the South and Southeast, and involves the removal of current low value stands without economic loss and preferably at a profit, preparation of site for replanting to improved species, and planting of new stock. The research program is located at Houghton, Michigan, and operates in cooperation with Michigan Technological University.

4. Virgin timber types with heavy logging debris, difficult access, high road construction costs.--The problem is characteristic of the forests of the Pacific Northwest and Alaska, but similar conditions may be found in California, and inland areas of the West. The research program is located in Seattle, Washington, and operates in cooperation with the University of Washington.

5. Large volumes of low value hardwoods on steep slopes, low densities per acre and interspersed with some high value hardwoods, most stands in small ownership patterns.--The problem is found typically in the Appalachian area of the eastern United States. The research program is located in Morgantown, West Virginia, and operates in cooperation with the University of West Virginia.

The program is designed to improve the efficiency and performance of forestry operations through the application of systems engineering. Systems analysis makes it possible to proceed with experimental hardware and prototype testing with considerable confidence. This technique also reduces the time required, hazards and costs of experimentation, and improves the returns therefrom.

The program is directed particularly to original applications designed to revolutionize forest production, protection, and utilization operations while considering other multiple use requirements. Targets for the next 5-year period are:

1. Twenty percent reduction in the costs of harvesting the Nation's timber crop, currently estimated at $1.6 billion annually. Estimated savings over a 20-year period - $6.4 billion.

2. Twenty percent reduction in costs of regeneration systems including seed collection and processing, nursery operations, and direct seeding techniques.

3. Ten percent reduction in logging accident frequency rate. Estimated saving - $1 million annually.

4. Reduce the miles of timber haul roads needed on National Forests in the Douglas-fir subregion by more than 11,000 miles. Estimated savings over a 20-year period - $330 million.

5. Capture 500 million board feet of the total of 840 million of annual allowable cut lost on timberlands not now loggable in the Douglas-fir region.

6. Capture an additional 440 million board feet of annual allowable cut in Alaska on National Forest areas that cannot be logged by conventional methods.

7. Complete development of engineering requirements for wood chip pipeline transportation systems to permit low cost reliable bulk delivery of raw material to processing plants.

8. Develop basic engineering data for production and use of special power sources needed to mechanize forestry operations in wildland areas. This work is basic to improving mechanizations and work conditions throughout the forestry field.

9. Ten percent reduction in cost of installation of watershed control and rehabilitation measures.

10. Engineering criteria and performance requirements for sewage, waste, and water supply services for wildland areas.

Close liaison is maintained with other domestic and foreign agencies engaged in forestry equipment research and development, and with equipment manufacturing industries and defense laboratories.

The Federal scientific effort devoted to research in this area totals 15.5 man-years intramural and 5.4 man-years extramural.

Progress--USDA and Cooperative Programs

While the recently established engineering research program is still in its infancy, there is ample evidence that the program can be effective in reducing unit costs of forestry operations while protecting or enhancing multiple use values.

Despite lack of additional funds, except for the special Appalachian program at Morgantown, to bring the program up to an efficient operating level, several well trained systems engineers have been recruited and added at project level. Initial tasks of the projects in program definition, problem analyses, and selection of highest value studies have been completed in most cases.

The results of even the first years of orientation and background work are beginning to appear even though hampered by proper sized and balanced staffs. Outputs in terms of inputs have been extraordinarily high, and the outlook for the future is even more promising.

The Morgantown, West Virginia, project forged ahead at a phenomenal rate under special Appalachian funding. An Engineering Research Symposium sponsored jointly with the West Virginia University attracted some 200 industry, association, academic, and Government representatives to a 2-day meeting in April 1966. Over $174,000 of cooperative aid projects were financed in the engineering and agricultural engineering schools of the West Virginia University. The terms of most of these studies are two to three years in length.

A contract has been awarded for construction of an engineering research laboratory at Houghton, Michigan, the first such structure in the program.

Some significant accomplishments follow:

1. Cutting Characteristics of Chain Saw Teeth.

This study consisted of the design, construction, instrumentation, and testing of a machine capable of measuring the forces existing on, and the energy requirements of, a single chain saw tooth as it cuts through green timber in a radial direction. The outstanding value of the study lies in the development of a method and technique to measure accurately the transient, fluctuating cutting forces and energy consumption. For the first time it has been possible to isolate the cutting forces in all three planes. The accomplishment opens the way to eventual improved design of chain saw teeth and other cutting devices. Potential annual savings to the logging industry through a 10 percent improvement (expected) in chain saw parts replacement and cost of maintenance is estimated at $1,850,000 per year. Industry interest is keen and appreciative.

2. Establishment of Research and Management Teams for Dissemination and Application of Aerial Logging Research Information and Techniques.

A program has been initiated by assignment of two NFA engineers to the Seattle Forest Engineering project to accelerate training of management personnel in, and application of, aerial logging research results. The engineers assigned will prepare guides for use by management in forecasting effects of, and in designing,

aerial logging system layouts. Management requirements and operational problems will be fed back to research through the engineers assigned for appropriate action. Additional engineers are expected to be assigned to other engineering research projects. Two engineers have been assigned to the Forest Products Laboratory on a similar mission.

3. Measurement of Dynamic Loads in Aerial Systems.

A system for telemetering strain gage outputs from aerial cables to tape recorders on the ground was developed and installed on a balloon logging operation at Reedsport, Oregon. The system can be used to measure loads and forces on skylines and other cable operated systems. Performance requirements for aerial systems can be obtained now for use by engineers and equipment designers in development of more efficient and safer aerial systems.

4. Design System for Aerial Cableways.

Analyses of aerial logging cableway installation, performance, failures, and operation indicated a need for an easily applied method of properly designing and operating single and multispan skylines. Such a method has been devised and results presented in the "Skyline Logging Handbook on Wire Rope Tensions and Deflections" (see list of publications). There has been widespread industry acceptance and worldwide interest in the method. Availability of the Handbook should result in more efficient and safer skylines and consequently more use of aerial systems so urgently needed to gain difficult access and to protect watershed and aesthetic values.

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V. FOREST ECONOMICS AND MARKETING RESEARCH

A. FOREST SURVEY

Problem

Basic statistics on timber resources, along with projections of timber demands and supplies, provide a means of judging the adequacy of existing forest policies and programs and the nature and magnitude of timber supply problems. The Forest Survey provides the only comprehensive nationwide data on the forest resource situation, including data by States and local regions on forest areas, ownership and condition of forest lands; the volume and quality of standing timber; trends in timber growth and mortality; and present and prospective amounts and kinds of timber cut. Because of rapid changes in timber demands and supplies and such factors as the growing competition for land, there is a growing need for more frequent periodic inventories and analyses of the timber situation for all forested areas throughout the Nation.

USDA and Cooperative Programs

This continuing long-range program of applied research is conducted largely through the Forest Experiment Stations of the Forest Service in cooperation with State conservation agencies, wood-using industries and other contributors of manpower and funds. All the 759 million acres of forest land in the United States has been inventoried at least once. Much of the 509 million acres of commercial forest land has been reinventoried at least once and over three-quarters has been reinventoried twice. Resurveys are being made at intervals of 8 to 15 years in different States. Comprehensive studies of the Nation's forest resources and outlook for future timber supplies and demands are made on an 8 to 10 year schedule.

Forest Service effort on timber resources surveys and appraisals involves about 37 scientist man-years annually.

Progress--USDA and Cooperative Programs

1. Field inventories

During the past year approximately 49 million acres of commercial forest land was inventoried in Alaska, Washington, California, Montana, Michigan, Kentucky, Mississippi, Oklahoma, Texas, Virginia, and Pennsylvania. Reports appraising the forest situation were issued for eight States or portions of States.

2. Increased timber supplies expected in Pacific Northwest

The forest lands of Washington, Oregon, Idaho, and western Montana, contain 1,123 billion board feet of sawtimber--about 44 percent of the U.S. supply. In 1962 timber industries in this region consumed about 21.2 billion board feet (International 1/4-inch log rule) of timber in producing about 51 percent of the Nation's softwood lumber, 87 percent of the softwood plywood, and 25 percent of the woodpulp. Projections of future timber supplies indicate that timber consumption will increase to 25 billion board feet by 1985, or 22 percent above 1962.

Woodpulp production is projected to rise about 2.4 times and softwood plywood 1.7 times. Lumber production, however, is expected to remain about the same as in 1962.

As a result of increased output per man hour, employment in the timber-based industries is projected to drop from about 158,000 workers in 1962 to 145,000 in 1985. The decline is especially rapid in the sawmill industry where employment is expected to fall from about 56,000 to 31,000. Employment in other timber-based industries is projected to increase in response to the anticipated rise in log output.

3. Softwood timber resource increasing in Louisiana

A new Forest Survey of Louisiana shows that during the late 1950's and early 1960's growth of softwood sawtimber in Louisiana was about double the cut. The resulting buildup in softwood sawtimber volume and the relatively large tree sizes available has provided a base for a substantial expansion of the timber industries in the State. Hardwood sawtimber, on the other hand, is being overcut and the total volume in 1964--some 20 billion board feet--was about 23 percent less than in 1954. Almost half of the volume of timber harvested was used for lumber and another two-fifths for pulpwood.

4. First comprehensive survey of Utah completed

The first complete inventory of Utah's forest revealed a volume of 19.5 billion board feet of sawtimber on 4.0 million acres of commercial forest land. A high percentage of stands are overmature. Timber cut in Utah amounted to only 12.6 million cubic feet in 1962, one-fifth of one percent of inventory; this is among the lowest cutting rates in the Rocky Mountain States. In recent years 90 percent of all roundwood cut was saw logs. Timber in Utah must be managed in relation to fragile soils, low values for timber, and high values for water, recreation, and forage.

5. Southern pulpwood output 61 percent of the Nation's total

Pulpwood output in the South rose to 28.8 million cords in 1964--an 8 percent increase over 1963. Georgia continues to be the leading pulpwood producing State in the South with 5.8 million cords Alabama was the second highest producer, with an output of 4.2 million cords. Pine roundwood, which comprised only 64 percent of the total in 1963, rose to 77 percent of the total in 1964.

6. Public Law 480 projects

During the past year several reports have been issued on the project, Improved Forest Survey Methods, conducted in Finland. These reports present much useful material on efficiency of various plot sizes in sampling and on methods of using aerial photographs for plot classification. This material has important applications to Forest Survey projects in this country.

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B. FOREST ECONOMICS

Problem

Expenditures for the protection, development, and production of timber and other resources on the forest lands of the United States now exceeds $400 million annually. Allocation of such funds among the many investment alternatives available is an increasingly important and difficult problem. The Nation's 4-1/2 million farmers, businessmen, professional people, and other owners or managers of private forest lands require economic guides for a wide range of forest management and land-use practices. Administrators of public forests require improved criteria and guides to efficiently allocate public funds among different forest practices, production units, and resource development opportunities. Of special importance is the development of procedures for integrating and balancing multiple uses of forest land to meet rapidly expanding public demands for timber, water, wildlife, recreation, and other goods and services.

USDA and Cooperative Programs

The Department conducts a continuing long-term program of applied forest economics research mainly through the Regional Forest Experiment Stations of the Forest Service. Forest economics research is closely coordinated with timber management research in studying problems of timber growing; with forest fire, disease, and insect research in appraising problems of forest protection; and with watershed, range and recreation research in evaluation of competing and multiple uses of forest lands. Cooperation is also maintained with the Economic Research Service, State Agricultural Experiment Stations, and forestry schools.

Forest Service effort devoted to research in this field totals 27 scientist man-years annually.

Progress--USDA and Cooperative Programs

1. Guides for evaluating reforestation and stand improvement on National Forests

A new handbook has provided guides for making economic appraisals of various opportunities for stand improvement and reforestation under varying conditions. Procedures are outlined for rating and comparing possible forest development projects and for deciding how much effort should be devoted to these aspects of timber management to yield highest rates of financial return. Although nontimber values often must be considered on National Forest projects, economic evaluations for timber production provide a benchmark for rating practices.

2. Proper thinning practices in red pine increase returns and add to timber supplies

Thinning practices and rotation ages, two factors that can be controlled by the forest manager, are major determinants of returns on timber-growing investments. Recently developed data for red pine in the Lake States demonstrate that under most conditions investment returns are highest if red pine stands are thinned regularly to 90 square feet of basal area per acre. Data also were developed to show how financial rotations, which must be estimated in evaluating thinning alternatives,

are affected by stand conditions, investment alternatives, costs, and prices. Application of these findings on the several million acres of red pine in the East would add substantially to long-run sawtimber supplies. Possible increases in timber output from improved thinning practices would also have the effect of reducing costs of growing red pine by $1 to $2 per thousand board feet.

Related guides describe how to estimate present values of incomes and costs in growing red pine trees for sale as pulpwood or sawtimber, and how to calculate expectation values and rates of return for a wide range of timber-growing conditions. Applicable to any type of ownership, the guides also illustrate how to compare investment opportunities in growing red pine; how to determine the amount one can afford to invest to buy land, establish and maintain a stand, or pay in annual taxes or other expenses; and how to estimate the cost of producing stumpage under specified conditions.

3. Economic guides for dwarfmistletoe control

Recently developed economic guides for control of dwarfmistletoe in ponderosa pine stands of the Pacific Northwest provide a basis for investment decisions in control programs. The cost and rate-of-return estimating procedures, based on time and cost studies of control operations in ponderosa pine stands, are intended for the practicing forester to aid in distributing available funds among management opportunities. Related economic guides for precommercial thinning of ponderosa pine in the Northwest also provide data on costs per acre and rate-of-return on investment in thinning.

4. Basic reference on mensurational characteristics of eastern white pine for economists and foresters

As part of a study of the economics of white pine management, a new bulletin has been issued to summarize available mensurational data for estimating site index, tree volume, stand growth, and yield of eastern white pine. This bulletin provides basic information for economists and others interested in calculating returns for different management practices involving white pine.

5. Computer-oriented systems help in allocating wild land resources

The allocation of wild land resources among multiple uses is a major problem for today's land managers. In a new attempt to solve this problem a system of parametric linear programming was developed to evaluate alternate policy decisions and land-improvement programs in the Southwest. A sequence of "Management Plans" afford the decision maker the opportunity to assess precisely the effect of decisions on a predetermined economic objective. This linear program and a map information assembly and display system program previously developed at the Pacific Southwest Forest and Range Experiment Station can be integrated to deal with large-scale and long-term wild land management problems.

6. Guides to getting acceptance of management practices among small private owners

Obtaining acceptance and adoption of forest management practices has been a major obstacle to increasing supplies of timber on the large areas of forest land in small private ownerships. A new study in the South offers guides for getting woodland management practices accepted among private owners. The young, the healthy, the educated, and the holders of large acreages were found to be most

receptive to the adoption of management practices. But in all groups some individuals can be identified who can be interested in forestry programs.

7. Sawmill operators own little timberland in Illinois

A study of sawmill operations in southern Illinois showed that mill operators experience little trouble in securing logs on the open market for continuous operation of their mills. Industrial ownership also was limited by the fact that very few large timber tracts are available for purchase, ownership of numerous small scattered tracts is impractical, and high costs of land investment would put heavy economic burdens on sawmill operators. The few mill operators who did own timberland generally produced small volumes of lumber, were farmers primarily, and timberland was usually acquired when land was purchased for farming.

8. Gauging the efficiency of forestry investments in depressed areas

There are extensive areas in the United States such as Appalachia where timber capital has been seriously depleted. In these areas there is particular need for objective methods of rating the potential efficiency of investments in forest rehabilitation and development. A recent study has provided an economic model for approximating the potential investment efficiency of selected wood-growing alternatives on several economic-condition classes of forest land in a section of the Cumberland Plateau in Tennessee. Results of the study indicate that most of the forest land in these counties is capable of returning 3 percent or more on investments in forest development. Increases in timber production also would provide much-needed employment and income.

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C. FOREST PRODUCTS MARKETING

Problem

The objective of forest products marketing research is to provide basic economic and marketing guides for expanding and improving use of wood products. It is intended to benefit timber producers and the processors, distributors, and consumers of forest products. Marketing research includes studies aimed at measuring current and potential demands for forest products; evaluating ways of reducing costs in the harvesting, processing, distribution and use of timber products; providing consumers with better products at lower prices; increasing incomes of woodland owners; and stimulating industrial development and economic growth in rural areas and in the Nation as a whole.

USDA and Cooperative Programs

This is a continuing program of applied research conducted in part by Regional Forest Experiment Stations and in part by the Washington staff of the Forest Service. Close cooperation is maintained with other scientists engaged in related marketing, utilization, engineering, and economic research within the Forest Service, other public agencies and forest products industries. Cooperation is maintained with the Statistical Reporting Service, State Agricultural Experiment Stations, forestry schools, Bureau of the Census, Federal Housing Administration, various forest products and building trade associations, and others who do research or have access to data pertinent to analyses of current and prospective markets for wood and other materials. Forest owners, loggers, processors, and consumers of wood products also cooperate by supplying production and marketing data.

Federal effort in this area of research totals 35 scientist man-years annually.

Progress--USDA and Cooperative Programs

1. Demand for hardwood veneer and plywood increasing

During the past decade U.S. consumption of hardwood veneer and plywood has about doubled, with most of this increase coming from Japan, the Philippines, and Southeast Asia. Since 1948 hardwood plywood imports have risen forty-fold to 60 percent of total U.S. consumption. Hardwood lumber imports have risen 39 percent to 5 percent of the U.S. market. Domestic hardwood veneer log production in this period has remained fairly constant at approximately one billion board feet a year. Projections of prospective future consumption show a continued increase in demand for hardwood veneer and plywood in fine furniture, paneling and related products.

Forest Survey statistics show that total growth of hardwood sawtimber in the United States has been rising steadily, but there are serious limitations as to species, size, and quality. Projected timber demands, growth, and inventories, moreover, point to accentuated timber supply problems for the hardwood veneer and plywood industry. Thus meeting projected demands for hardwood veneer and plywood will require increased imports and improved timber management and processing technology.

2. Impact of log exports to Japan on Pacific Northwest economy

Recent increases in log exports from the U.S. to Japan have raised many questions as to the impact of these exports on the economy of the Pacific Northwest. A study of a sample of logs representative of the species, grades, and sizes recently exported to Japan showed that the average value of the sample logs loaded aboard ship, ready for export, was $99.70. The average value of products that could have been obtained through domestic processing of the same logs was estimated at $95.24. In terms of direct employment, however, it was estimated that domestic processing of the sample logs into surfaced, kiln dried lumber would generate from 8.01 to 9.76 man-hours of work per thousand board feet, depending on mill size, compared to 3.0 man-hours of direct employment in log exporting. More than 90 percent of the export volume was made up of No. 2 and No. 3 saw logs. Less than 4 percent consisted of peeler and select grade logs. Over 80 percent of the logs were under 22 inches in diameter, and more than 75 percent of the volume was hemlock and white fir. Only 9 percent was Douglas-fir.

3. Markets for wood products in Hawaii--current and future

A cooperative Forest Service-State of Hawaii study shows that residential construction and the manufacture of furniture and pallets are the major Hawaiian markets for lumber and plywood. During recent years, lumber consumption has averaged about 80 million board feet of softwoods and 7 million board feet of hardwoods. Only one million board feet of this volume is domestically produced hardwood lumber and the remainder is imported. Rising requirements for lumber and plywood represent opportunities for a substantial expansion of the State's hardwood timber industry.

4. Operations research--the way to higher sawmill profits

Sawmill manager's decisions on how to saw different classes of logs for maximum profit must be based on (1) the amount, quality, and cost of logs, (2) possible sawing patterns and their yields, (3) time available on each piece of mill equipment, and (4) markets and prices. These factors were considered simultaneously in analyzing the operations of a high-speed southern pine sawmill. Batches of logs of varying diameter, grade, density, and location in the tree were processed by several sawing patterns into different product mixes. Inputs, outputs, and time required for each operation were measured. Optimun sawing patterns for each class of logs were then determined by linear programming.

Sawing each class of logs by the optimum sawing pattern for the class yielded $1,647 total revenue per hour over-and-above the cost of raw material. This revenue came from 31.5 thousand board feet of lumber, 2.3 thousand board feet of timbers, and 38.5 tons of chips. The analysis also showed how changes in operating procedure, such as increasing the log supply, selling logs for pulpwood, changing lumber sales strategy, purchasing low-grade lumber, adding equipment, and changing relative prices of boards and dimension would change optimum sawing patterns for the various classes of logs. The system of analysis developed in this study can be used to advantage by many sawmill operators as an aid in making better management decisions.

5. Better planning and management can reduce Appalachian logging costs

An analysis of costs and returns on operations in southeast Kentucky shows a cost distribution of 29 percent for stumpage, 31 percent for labor, and 40 percent for equipment. Total costs per thousand board feet (Doyle) amounted to $35.82, while profits amounted to 10.5 percent of receipts. This analysis also showed that high productivity in logging depends on careful planning, effective supervision, and use of modern equipment. More efficient use of men and equipment on the operations studied could have resulted in a 25 percent increase in production and a doubling of the margin for profit and risk.

6. Both buyers and sellers benefit from use of Forest Service hardwood log grades

Recently completed studies at five Appalachian hardwood sawmills show that local log-grading systems misclassified the quality of 42 percent of the volume in 1,164 sample logs. As a result operators underpaid suppliers for some of the logs purchased and overpaid others. Average net returns at the five sample mills could have been increased nearly $4 per thousand board feet by using the more accurate standard Forest Service log grades. Data taken at 13 sample mills indicate that the Forest Service log-grading system can be readily applied by the log scaler at an average cost of less than 30 cents per thousand board feet of logs. This study also showed that one man is more efficient than a two-man scaling and grading crew.

7. Tomorrow's crosstie--wood or concrete?

A recently completed analysis of markets for railroad crossties shows that consumption dropped from an average of 48.4 million ties annually during the 1940's to 14.5 million ties in 1961. Annual tie consumption has recently increased rapidly, however, to a current level at about 20 million ties, and demands for ties continue to exceed supplies. However, many sawmills that formerly produced crossties have gone out of business or have shifted to other products. The current shortage of wood crossties has encouraged the testing of concrete ties in a number of tracks in the eastern United States, and unless ways are found to improve the utility of wood ties, and production is increased substantially, it seems likely that concrete ties will continue to penetrate this market. Research is therefore underway to determine possibilities for more efficient and profitable systems for producing crossties, and the practicability of using new designs of solid wood or laminated ties.

8. Opportunities good for increased pulp and paper production in Illinois

A recent analysis of markets, wood supplies, production costs, and other factors shows a potential for a substantial increase in pulp and paper production in southern Illinois. Available timber resources could sustain additional pulping capacity of 1,500 to 2,500 tons per day. Water supplies and rates of flow of major rivers are adequate for most pulping processes, good transportation facilities are available, and labor and power are available at reasonable costs.

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WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U. S. D. A.

May 1, 1965 to April 30, 1966

Work and line project number		Work and line project titles	Work locations	Line projects summary index
CPO	FS			
		SILVICULTURE OF EASTERN FOREST TYPES		
FS 1 1-1 (NC)	FS-NC-1101	Site requirements of northern conifers and hardwoods	St. Paul, Minnesota	
FS 1 1-2 (NC)	FS-NC-1102	Silviculture of northern hardwoods in the Lake States	Marquette, Michigan	
FS 1 1-3 (NC)	FS-NC-1103 (Rev.)	Silviculture of northern conifers and aspen	Grand Rapids, Minn.	I, A-1, A-2
FS 1 1-4 (NC)	FS-NC-1104 (Rev.)	Silviculture of mixed hardwoods	East Lansing, Mich.	
FS 1 1-5 (NC)	FS-NC-1105	Plantation management of Lake States conifers	East Lansing, Mich.	
FS 1 1-6 (NC)	FS-NC-1106	Seedling physiology and establishment of central hardwoods	Ames, Iowa	I, A-1
FS 1 1-10 (NC)	FS-NC-1108	Culture of black walnut	Carbondale, Illinois	I, A-2, A-3, A-4
FS 1 1- (NC)	FS-NC-1107	Soil and site requirements for walnut	Carbondale, Illinois	I, A-1
FS 1 1-11 (NC)	FS-NC-1109	Silviculture of oak-hickory forests	Columbia, Missouri	I, A-7, B-1
FS 1 1-12 (NE)	FS-NE-1101	Silviculture of spruce and fir	Orono, Maine	I, A-3
FS 1 1-14 (NE)	FS-NE-1103	Silviculture of northern Appalachian hardwoods	Parsons, W. Virginia	I, A-4, A-5
FS 1 1-15 (NE)	FS-NE-1104	Silviculture of northern hardwoods in the Northeast	Durham, N. Hampshire	I, A-1, A-3, A-7, B-1, B-2, D-2
FS 1 1-19 (NE)	FS-NE-1108	Silviculture of black cherry and red maple	Warren, Penna.	I, A-2
FS 1 1- (NE)	FS-NE-1109	Silviculture of mountain hardwoods	Berea, Kentucky	I, A-2
FS 1 1-20 (SE)	FS-SE-1101	Silviculture of Virginia and shortleaf pine	Blacksburg, Virginia	I, A-1
FS 1 1-21 (SE)	FS-SE-1102	Silviculture of southern Appalachian hardwoods	Asheville, N. C.	I, C-3
FS 1 1-22 (SE)	FS-SE-1103	Interrelationships of soils and trees in the Piedmont	Res. Triangle, N. C.	I, A-1
FS 1 1-25 (SE)	FS-SE-1106	Silviculture of Coastal Plain timber types	Charleston, S. C.	I, A-3
FS 1 1-26 (SE)	FS-SE-1107	Silviculture of southern Piedmont hardwoods	Athens, Georgia	I, A-2, D-4
FS 1 1-27 (SE)	FS-SE-1108	Silviculture of Piedmont loblolly pine, including plantation management	Macon, Georgia	I, B-3
FS 1 1-29 (SE)	FS-SE-1110	Silviculture of slash pine type	Olustee, Florida	I, A-3, A-4, B-1, B-3
FS 1 1-34 (SE)	FS-SE-1111	Pine establishment in sandhills	Marianna, Florida	
FS 1 1-30 (SO)	FS-SO-1102	Artificial regeneration of southern pines	Alexandria, Louisiana	I, A-2, A-5
FS 1 1- (SO)	FS-SO-1103	Longleaf pine silviculture	Auburn, Alabama	
FS 1 1-31 (SO)	FS-SO-1106	Silviculture of southern hardwoods	Stoneville, Mississippi	
FS 1 1-32 (SO)	FS-SO-1107	Silviculture of loblolly pine in the mid-South	Crossett, Arkansas	
FS 1 1-33 (SO)	FS-SO-1101	Silviculture of the Ozark pine type	Harrison, Arkansas	I, A-1
FS 1 1-43 (SO)	FS-SO-1108	Technology of eastern forest tree seed	State College, Miss.	
FS 1 1-35 (SO)	FS-SO-1104	Silvicultural aspects of combining timber and game	Nacogdoches, Texas	
FS 1 1-36 (SO)	FS-SO-1105	Artificial regeneration of Cumberland Planteau hardwoods	Sewannee, Tennessee	
FS 1 1-37 (ITF)	FS-ITF-1101	Silviculture of tropical trees	Rio Piedras, P. R.	I, A-2
FS 1 1-39 (ITF)	FS-ITF-1102	Applied tropical forestry	Rio Piedras, P. R.	

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WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
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Work and line project number		Work and line project titles	Work locations	Line projects summary index
CPO	FS			
		SILVICULTURE OF EASTERN FOREST TYPES (continued)		
FS 1 1-38 (WO)	FS-WO-1101	Physiology of tree growth, nutrition, and mycorrhizal relationships	Beltsville, Maryland	
FS P-2	FS P-2	Pioneering research on physiology of wood formation	Rhinelander, Wisconsin	
FS P-6	FS P-6	Pioneering research on forest soils	Res. Triangle, N. C.	
FS 1 1-40 (WO-Gr.)	FS-WO-1102 (Gr.)	Uptake, translocation, and cycling of residual pesticides by woody plants	Athens, Georgia	
FS 1 1-42 (WO-Gr.)	FS-WO-1104 (Gr.)	Biosynthesis of cellulose in trees	Gainesville, Florida	
		SILVICULTURE OF WESTERN FOREST TYPES		
FS 1 2-1 (NOR)	FS-NOR-1201	Silviculture of coastal forests in Alaska	Juneau, Alaska	I, A-2
FS 1 2-2 (NOR)	FS-NOR-1202	Silviculture of interior Alaska forests	College, Alaska	
FS 1 2-3 (PNW)	FS-PNW-1201	Seeding, planting, and nursery practices in the Pacific Northwest	Corvallis, Oregon	I, A-2
FS 1 2-5 (PNW)	FS-PNW-1203	Silviculture of lodgepole and ponderosa pine and interior-mixed conifers	Bend, Oregon	I, A-7, B-1
FS 1 2-6 (PNW)	FS-PNW-1204	Silviculture of true fir-mountain hemlock and Sitka spruce-western hemlock types	Corvallis, Oregon	I, A-4, A-6, A-7
FS 1 2-7 (PNW)	FS-PNW-1205	Silviculture of mixed pines and Douglas-fir	Roseburg, Oregon	
FS 1 2-8 (PNW)	FS-PNW-1206	Brushfield reclamation	Corvallis, Oregon	I, A-5
FS 1 2-9 (PNW)	FS-PNW-1207	Silviculture of young-growth Douglas-fir and related species	Olympia, Washington	I, A-3, A-4, A-7, B-1
FS 1 2-10 (PNW)	FS-PNW-1208	Prevention and control of animal damage to forest trees	Olympia, Washington	I, A-6
FS 1 2-12 (PSW) (supersedes	FS-PSW-1201 (Rev.) 1201 and 1202)	Silviculture of Sierra Nevada conifer types	Redding, California	I, A-2, A-3, A-4
FS 1 2-14 (PSW)	FS-PSW-1203	Silviculture of redwood and Douglas-fir	Arcata, California	I, A-3
FS 1 2-16 (PSW)	FS-PSW-1205 (Rev.)	Timber and watershed research in Hawaii	Honolulu, Hawaii	
FS 1 2-17 (INT)	FS-INT-1201	Silviculture of western white pine	Moscow, Idaho	I, B-1
FS 1 2-18 (INT)	FS-INT-1202	Silviculture of ponderosa pine and interior Douglas-fir	Boise, Idaho	I, A-3
FS 1 2-19 (INT)	FS-INT-1203	Silviculture of lodgepole pine in the northern and intermountain regions	Bozeman, Montana	
FS 1 2-20 (INT)	FS-INT-1204	Silviculture of western larch and Engelmann spruce	Missoula, Montana	I, A-3
FS 1 2-27 (INT)	FS-INT-1205	Forest ecosystem management and protection in Northern Rocky Mountain and Intermountain regions	Ogden, Utah	

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CPO	FS			
		SILVICULTURE OF WESTERN FOREST TYPES (continued)		
FS 1 2-21 (RM)	FS-RM-1201	Silviculture of spruce-fir and lodgepole pine in the central Rocky Mountains	Ft. Collins, Colorado	
FS 1 2-22 (RM)	FS-RM-1202	Silviculture of mixed conifers and aspen	Ft. Collins, Colorado	
FS 1 2-23 (RM)	FS-RM-1203	Silviculture of ponderosa pine in the Southwest	Flagstaff, Arizona	
FS 1 2-25 (RM)	FS-RM-1205	Silviculture of Black Hills ponderosa pine	Rapid City, S. Dakota	
FS 1 1-41 (WO-Gr.)	FS-WO-1103 (Gr.)	The basis for the palatability of ruminant forage plants	Davis, California	
FS 1 1-44 (WO-Gr.)	FS-WO-1105 (Gr.)	An ecological study of forest vegetation in western Wyoming	Pullman, Washington	
		TIMBER MEASUREMENT		
FS 1 3-1 (PNW)	FS-PNW-1301 (Rev.)	Measurement and related timber management techniques in the Northwest	Portland, Oregon	I, B-1, B-2
FS 1 3-2 (INT)	FS-INT-1301	Measurement studies of forest timber types and species in the northern Rocky Mountain and Intermountain regions	Moscow, Idaho	
FS 1 3-3 (NE)	FS-NE-1301	Measurement studies of northeastern conifers and hardwoods	Upper Darby, Penna.	
FS 1 3-4 (SO)	FS-SO-1301	Measurement studies of southern pines and hardwoods	Harrison, Arkansas	I, B-2
FS 1 3-5 (RM)	FS-RM-1301	Timber measurement and management planning procedures for timber types and species in the Rocky Mountains and southwestern region	Ft. Collins, Colorado	
FS 1 3-6 (PSW)	FS-PSW-1301 (Rev.)	Measurement and analysis techniques for management planning	Berkeley, California	
FS 1 3-8 (NE)	FS-NE-1302	Timber measurement and management planning procedures for eastern hardwoods	Columbus, Ohio	I, B-1
FS 1 3-9 (SE)	FS-SE-1301	Measurement studies of forests of the Southeast	Res. Triangle, N.C.	
FS P-1	FS P-1	Pioneering research in forest measurements	Berkeley, California	

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CPO	FS			
		FOREST GENETICS		
FS 1 4-1 (PSW)	FS-PSW-1401	Genetics of western conifers	Berkeley, California	I, C-1, C-2
FS 1 4-2 (NC)	FS-NC-1401	Genetics of northern forest trees	Rhinelander, Wis.	I, C-1
FS 1 4-9 (NC)	FS-NC-1402	Tree improvement of black walnut and other high-quality hardwoods	Carbondale, Illinois	I, C-1
FS 1 4-3 (NE) (supersedes 1401 and 1105)	FS-NE-1401 (Rev.)	Tree improvement of northeastern conifers and hardwoods	Durham, N. H.	I, A-2
FS 1 1-28 (SE)	FS-SE-1401	Southern pine tree improvement	Macon, Georgia	I, C-1
FS 1 4-4 (SO)	FS-SO-1401	Genetics of southern pines and hardwoods	Gulfport, Miss.	I, C-1, C-2, C-3
FS 1 4-5 (WO)	FS-WO-1401	Identification, classification, and distribution of forest trees	Washington, D. C.	
FS 1 4-6 (WO-Gr.)	FS-WO-1402 (Gr.)	Breeding pines for resistance to Neodiprion sawflies	New Haven, Conn.	
FS 1 4-6 (WO-Gr.)	FS-WO-1403 (Gr.)	Resistance of pines to the white pine weevil	University Park, Pennsylvania	
FS1 4-10 (WO-Gr.)	FS-WO-1404 (Gr.)	Physiology and biochemistry of root initiation in black walnut	Lafayette, Indiana	
		TIMBER-RELATED CROPS		
FS 1 5-1 (NE)	FS-NE-1501	Maple sap production and related tree improvement	Burlington, Vermont	I, A-2, D-2
FS 1 5-4 (NE)	FS-NE-1502	Christmas trees and other decorative or medicinal plants	Berea, Kentucky	
FS 1 5-2 (SE)	FS-SE-1501 (Rev.)	Naval stores gum production and physiology	Olustee, Florida	I, C-1
FS 1 5-7 (SE)	FS-SE-1502	Naval stores tree improvement	Olustee, Florida	I, D-1
FS 1 2-24 (RM) (formerly 1204)	FS-RM-1501	Shelterbelts research in southern and central Great Plains	Lincoln, Nebraska	I, D-3
FS 1 2-26 (RM) (formerly NC (LS) - 1501)	FS-RM-1502	Shelterbelts research in northern Great Plains	Bottineau, N. Dakota	I, D-3
FS 1 5-3 (WO-Gr.)	FS-WO-1501 (Gr.)	Factors influencing carbohydrate metabolism of sugar maple	Burlington, Vermont	
FS 1 5-6 (WO-Gr.)	FS-WO-1502	The chemistry of resin acids from oleoresin	Athens, Georgia	

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CPO	FS			
		PL 480 PROJECTS		
S3-FS- 6		Mineral nutrition of Pinus elliottii	São Paulo, Brazil	
S4-FS- 3		Investigation in rooting and growth induction of short shoots of Pinus radiata	Santiago, Chile	
S4-FS- 6		Biosynthesis of terpenes in Pinus radiata	Santiago, Chile	
S4-FS- 7		Effect of growth substances in pine meristems	Santiago, Chile	
S5-FS- 4		Basic studies of the physiological changes in the transition from juvenile to mature stage in certain forest trees	Bogata, Colombia	
S5-FS- 5		Studies on the production of homozygons lines of pines	Bogata, Colombia	
E8-FS-45		Population study concerning spruce with special reference to the variation in the characteristics of wood	Helsinki, Finland	
E8-FS-46		The value of alder in adding nitrogen in forest soils	Helsinki, Finland	
E8-FS-47		Induced polyploidy and other mutations in birch, Betula spp.	Turku, Finland	
E8-FS-48		DNA and RNA studies on Scotch pine with special attention to finding a method to increase flowering	Turku, Finland	
E8-FS-49		The role of soil fungi in the formation of different humus types	Helsinki, Finland	
E8-FS-50		Pollen dispersal and its significance in silviculture and genetics	Helsinki, Finland	
E8-FS-51		Effect of silvicultural practices upon the arthropod, annelid, and nematode populations in forest litter and soil	Helsinki, Finland	
E8-FS-64		The use of serological technique in detecting incompatibility barriers in the pines	Helsinki, Finland	
E11-FS-1		Reconnaissance breeding in certain hard pines of the Mediterranean area	Thessaloniki, Greece	
E11-FS-2		Nutritional studies of forest trees under various soil and nutrient solution conditions	Athens, Greece	
A7-FS-10		Investigations on mycorrhizae-forming fungi with special reference to conifers in India	Dehra Dun, India	
A7-FS-11		Investigations on the use of auxins in vegetative reproduction of forest plants	Chandigarh, India	
A7-FS-12		Cytology of some Himalayan hardwoods and cytological and morphological differences or similarities in ecotypes or clines of Himalayan forest trees	Chandigarh, India	

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CPO	FS			
		PL 480 PROJECTS (continued)		
A7-FS-15		Cooperative tree improvement research on teak	Dehra Dun, India	
A7-FS-35		Techniques for inducing mutations and polyploidy in some species of importance in forestry	Dehra Dun, India	
A7-FS-36		Tissue and cell culture of pines and allied conifers	Delhi, India	
A10-FS-5		Factors controlling the annual rhythm of wood production	Jerusalem, Israel	
A10-FS-7		Mechanisms of drought tolerance and drought avoidance in conifers of the Mediterranean zone and the arid West of the United States	Rehovot, Israel	
A10-FS-8		The development of techniques for the vegetative propagation of pine trees by means of needle fascicles	Jerusalem, Israel	
A10-FS-10		Effect of transpiration retardants on certain physiological processes of forest seedlings and other plants	Jerusalem, Israel	
A10-FS-15		Morphological and anatomical changes related to resin stimulation	Jerusalem, Israel	
E15-FS-3		Factors affecting the difficult rooting of cuttings in some poplars (i.e. Populus deltoides v. angulata, P. alba, P. tremula) and their hybrids	Rome, Italy	
E15-FS-6		The problem of incompatibility in grafting of forest trees, especially pines	Florence, Italy	
E15-FS-8		Comparative studies of the photosynthetic efficiences of poplar hybrids	Milan, Italy	
A13-FS-1		The fundamental mechanism of root-primordia formation of cuttings	Suwon, Korea	
E21-FS-17		Investigations of pure culture of mycorrhizal fungi of pine (Pinus sylvestris L.)	Warsaw, Poland	
E21-FS-20		Population study of spruce in Poland	Warsaw, Poland	
E21-FS-22		Influence of sowing of lupine on tree growth	Warsaw, Poland	

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CPO	FS			
		PL 480 PROJECTS (continued)		
E21-FS-23		Decomposition of forest litter and thick moss layers in spruce and pine stands	Warsaw, Poland	
E21-FS-24		Studies in wood formation with emphasis on seasonal changes	Warsaw, Poland	
E21-FS-26		A survey of endogenous growth substances in certain forest trees	Torun, Poland	
E21-FS-31		Studies on the variability of photosynthesis of pine trees during development under different conditions of growth	Warsaw, Poland	
E21-FS-32		Effect of gibberellin on auxin metabolism and its relation to growth of Scots pine seedlings (Pinus sylvestris)	Poznan, Poland	
E21-FS-33		Variation between Picea abies provenances in their ability to utilize mineral nutrients under competitive conditions	Poznan, Poland	
E25-FS-14		Ontogenesis of enzymes induced in pine seed through cold stratification	Madrid, Spain	
E25-FS-15		Minor elements distribution in cellular fluids of floral and foliar tissue of trees	Madrid, Spain	
E25-FS-16		Isolation and identification of plant hormones associated with callus and root formation	Santiago, Spain	
E25-FS-20		The determination of levels of boron, manganese, and molybdenum sufficient for growth of Monterey pine (Pinus radiata)	Madrid, Spain	
E25-FS-23		Spanish contribution to multilingual forest terminology with Hispano-American terms	Madrid, Spain	
E25-FS-24		Biosynthesis of terpenes in pine	Granada, Spain	
E25-FS-25		The determination of levels of Fe, Cu, and Zn sufficient for the growth of Monterey pine	Madrid, Spain	
A6-FS-2		The genus Abies	Taipei, Taiwan	

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CPO	FS			
		FOREST SOIL AND WATER RESEARCH		
FS 1 6-1 (NOR)	FS-NOR-1601	Erosion and sedimentation, coastal forests	Juneau, Alaska	II, A-2-a
FS 1 6-2 (PNW)	FS-PNW-1601	Water yield and erosion - Columbia River	Wenatchee, Washington	II, A-2-a
FS 1 6-3 (PNW)	FS-PNW-1602	Watershed logging methods and streamflow - western Cascades	Corvallis, Oregon	II, A-2-a
FS 1 6-39 (PNW)	FS-PNW-1603	Pesticides - soil and water	Corvallis, Oregon	II, A-2-a
FS 1 6-4 (PSW)(R)	FS-PSW-1601(Rev.)	Water yield improvement, conifer zone	Berkeley, California	II, A-1-b
FS 1 6-5 (PSW)(R)	FS-PSW-1602(Rev.)	Hydrologic analysis methods	Berkeley, California	II, A-1-b,2-a,2-c
FS 1 6-6 (PSW)(R)	FS-PSW-1603(Rev.)	Flood and sediment reduction, conifer zone	Berkeley, California	II, A-1-c,2-a
FS 1 6-7 (PSW)(R)	FS-PSW-1604(Rev.)	Brushland flood and sediment reduction - Southwest	Glendora, California	II, A-3-d
FS 1 6-8 (PSW)(R)	FS-PSW-1605(Rev.)	Brushland water yield improvement - Southwest	Glendora, California	II, A-3-d
FS 1 6-10 (INT)(R)	FS-INT-1601(Rev.)	Streamflow regulation in Northern Rocky Mountain forests	Moscow, Idaho	
FS 1 6-11 (INT)	FS-INT-1602	Soil stabilization, logging - Northern Rocky Mountains	Boise, Idaho	II, A-2-b
FS 1 6-12 (INT)(R)	FS-INT-1603(Rev.)	Watershed rehabilitation and protection - high rangelands	Logan, Utah	II, A-3-b
FS 1 6-14 (INT)(R)	FS-INT-1605(Rev.)	Water yield improvement - Great Basin	Logan, Utah	II, A-1-c
FS 1 6-16 (RM)	FS-RM-1601	Alpine snow and avalanche research	Fort Collins, Colorado	II, A-1-a
FS 1 6-17 (RM)	FS-RM-1602	Water yield snowpack timber - Rocky Mountains	Fort Collins, Colorado	II, A-1-b
FS 1 6-18 (RM)(R)	FS-RM-1603(Rev.)	Water yield, soil stabilization - Big Horn, North Platte	Laramie, Wyoming	II, A-1-a,1-b
FS 1 6-19 (RM)	FS-RM-1604	Watershed rehabilitation - Southwest	Albuquerque, New Mexico	II, A-3-b
FS 1 6-21 (RM)(R)	FS-RM-1606(Rev.)	Water yield improvement - Southwest	Tempe, Arizona	II, A-1-c
FS 1 6-38 (RM)	FS-RM-1608	Improvement of water yields and stabilization	Rapid City, S. Dak.	
FS 1 6-43 (NC)	FS-NC-1601	Runoff reduction and streamflow improvement - nonglaciated	La Crosse, Wisconsin	II, A-1-b,2-a
FS 1 6-23 (NC)	FS-NC-1602	Bog and swamp hydrology	Grand Rapids, Minn.	II, A-4
FS 1 6-42 (NC)	FS-NC-1603	Ground water hydrology and streambank erosion	Cadillac, Michigan	II, A-1-b,3-a
FS 1 6-27 (NE)(R)	FS-NE-1601(Rev.)	Water yield improvement - New England	Laconia, New Hampshire	II, A-1-b
FS 1 6-28 (NE)(R)	FS-NE-1602(Rev.)	Floods and water yield - northern Appalachians	Parsons, West Virginia	II, A-1-c,2-a
FS 1 6-29 (NE)(R)	FS-NE-1603(Rev.)	Watershed correlation and synthesis	Upper Darby, Penn.	II, A-1-c,2-a
FS 1 6-30 (NE)(R)	FS-NE-1604(Rev.)	Stream regimen and water yields - Northeast	Syracuse, New York	II, A-1-b
FS 1 6-25 (NE)	FS-NE-1605	Strip-mined area restoration	Berea, Kentucky	II, A-3-c
FS 1 6-26 (NE)	FS-NE-1606	Management of storm runoff	Columbus, Ohio	
FS 1 6-31 (SE)(R)	FS-SE-1601(Rev.)	Water yield improvement, mountains - Piedmont	Franklin, N. C.	II, A-1-c
FS 1 6-32 (SE)(R)	FS-SE-1602(Rev.)	Wetland improvement	Charleston, S. C.	II, A-4

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		FOREST SOIL AND WATER RESEARCH		
FS 1 6-34 (SO)	FS-SO-1601	Water timing - Ozark-Ouachita	Harrison, Arkansas	
FS 1 6-35 (SO)	FS-SO-1602	Coastal plain hydrology - South	Oxford, Mississippi	
FS 1 6-36 (SO)	FS-SO-1603	Watershed rehabilitation - Coastal Plain	Oxford, Mississippi	II, A-3-a
FS 1 6-37 (SO)	FS-SO-1604	Management of erosive watersheds	Oxford, Mississippi	II, A-3-a
		P. L. 480 PROJECTS		
	A10-FS-9	Monographic revision of the genus Tamarix	Israel	II, A-5-a
	A10-FS-13	Study of difference in effects of forest and other vegetative covers on water yield	Israel	II, A-5-b
	E21-FS-36	Seasonal variability of soil moisture and levels of groundwater table on lowland areas, as they affect water use, growth and development of pine stands	Poland	II, A-5-c
		FOREST RECREATION RESEARCH		
FS 1 9-1 (PSW)(R)	FS-PSW-1901(Rev.)	Recreation management guides - California	Berkeley, California	II, B-1,2
FS 1 9-2 (NC)	FS-NC-1901	Recreation - North Central	St. Paul, Minnesota	II, B-1,2
FS 1 9-3 (NC)	FS-NC-1902	North Central - University of Michigan Cooperative Recreation Research Unit	Ann Arbor, Michigan	
FS 1 9-4 (NE)	FS-NE-1903	Small woodland recreation	Berea, Kentucky	II, B-3
FS 1 9-5 (NE)(R)	FS-NE-1901(Rev.)	Forest recreation market analyses - Northeastern	Warren, Pennsylvania	
FS 1 9-6 (NE)	FS-NE-1902	Syracuse recreation project	Syracuse, New York	II, B-1,3
FS 1 9-7 (WO)	FS-WO-1901	Evaluation of economic and other factors pertinent to planning and administering forest recreation use	Washington, D. C.	
FS 1 9-8 (INT)	FS-INT-1901	Recreation management and planning - Intermountain	Ogden, Utah	
FS 1 9-9 (INT)	FS-INT-1902	Forest recreation research unit in cooperation with Utah State University	Logan, Utah	II, B-1
FS 1 9-11 (PNW)	FS-PNW-1901	Wilderness recreation dynamics	Portland, Oregon	
FS 1 9-13 (SE)	FS-SE-1901	Forest recreation management research	Asheville, N. C.	II, B-2
	FS-SE-1902	Cooperative forest recreation unit	Raleigh, N. C.	
FS 1 9-15 (RM)	FS-RM-1901	Forest recreation research - Rocky Mountains	Fort Collins, Colo.	
FS 1 9-16 (WO)(Gr)	FS-WO-1902(Gr)	Some effects of landscape enhancement on timber production	Cambridge, Mass.	
FS 1 9-17 (WO)(Gr)	FS-WO-1903(Gr)	Measurement of the esthetic appeal of managed forest and wild land roadside environments	Gainesville, Florida	

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		RANGE MANAGEMENT RESEARCH		
FS 1 7-1 (PNW)	FS-PNW-1701	Range ecology and management - Northwest	La Grande, Oregon	II, C-1-a,3-a
FS 1 7-3 (PSW)(R)	FS-PSW-1701(Rev.)	Management of perennial grass ranges	Berkeley, California	
FS 1 7-4 (PSW)(R)	FS-PSW-1702(Rev.)	Management of annual plant and related ranges	Fresno, California	II, C-3-b,4,D-2
FS 1 7-7 (INT)	FS-INT-1701	Sagebrush, cheatgrass, and granitic soil ranges	Boise, Idaho	II, C-3-a,4,D-1
FS 1 7-8 (INT)	FS-INT-1702	Northern Rocky Mountain grasslands	Bozeman, Montana	II, C-1-a,3-a
FS 1 7-9 (INT)	FS-INT-1703	Salt-desert shrub, sagebrush grass, and pinyon-juniper ranges	Provo, Utah	II, C-2-a,3-b,5
FS 1 7-10 (INT)	FS-INT-1704	Management of mountain herbland, brushland, and aspen ranges	Logan, Utah	II, C-1-a,2-b,5
FS 1 7-11 (RM)	FS-RM-1701	Mountain ranges - central Rockies	Fort Collins, Colorado	II, C-1-a,2-c,3-b
FS 1 7-12 (RM)	FS-RM-1702	Range biometry	Fort Collins, Colorado	
FS 1 7-13 (RM)	FS-RM-1703	Alpine and subalpine ranges	Laramie, Wyoming	II, C-1-a,2-b,3-b
FS 1 7-14 (RM)	FS-RM-1704	Southwestern seeded ranges	Albuquerque, New Mexico	II, C-4
FS 1 7-15 (RM)	FS-RM-1705	Southwestern chaparral, woodland, and forest ranges	Flagstaff, Arizona	II, C-1-a,2-a,3-a,4
FS 1 7-16 (RM)	FS-RM-1706	Semidesert cattle ranges	Tucson, Arizona	II, C-1-a,2-a,3-a,4
FS 1 7-21 (RM)	FS-RM-1707	Range inventory and evaluation	Fort Collins, Colorado	
FS 1 7-17 (NC)	FS-NC-1701	Range evaluation and management	Columbia, Missouri	II, C-1-a,2-a,2-c, 3-b,D-3-a
FS 1 7-18 (SE)(R)	FS-SE-1701(Rev.)	Multiresources management of the pine-wiregrass type	Fort Myers, Florida	II, C-3-b,4
FS 1 7-19 (SO)	FS-SO-1701	Southern pine cattle ranges	Alexandria, Louisiana	II, C-2-c
FS 1 7-20 (WO)	FS-WO-1701	Range plant taxonomy	Washington, D. C.	II, C-1-b
		P. L. 480 PROJECTS		
	A10-FS-6	Germination of seeds of desert plants	Jerusalem, Israel	
	E25-FS-1	Studies of botany, ecology, biology, and pascicology of the principal existing species in the spontaneous pastur-grounds of the mountains of our semiarid regions	Madrid, Spain	

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CPO	FS			
		WILDLIFE HABITAT RESEARCH		
FS 1 8-1 (PNW)	FS-PNW-1801	Big-game habitat - Pacific Northwest	La Grande, Oregon	II, D-3-a,3-b
FS 1 8-3 (PSW)(R)	FS-PSW-1801(Rev.)	Wildlife habitat research - California	Berkeley, California	II, D-2,3-b
FS 1 8-4 (INT)	FS-INT-1801	Deer winter range - Idaho	Boise, Idaho	II, D-1,3-c
FS 1 8-5 (INT)	FS-INT-1802	Northern Rockies forest wildlife habitat	Missoula, Montana	II, D-1,3-a,3-c
FS 1 8-6 (INT)	FS-INT-1803	Game range restoration and wildlife-livestock relations	Provo, Utah	II, D-1
FS 1 8-7 (RM)	FS-RM-1801	Forest game and fish habitat - Central Rockies	Fort Collins, Colorado	
FS 1 8-8 (RM)	FS-RM-1802	Wildlife habitat - southwestern vegetation types	Tempe, Arizona	II, D-3-b
FS 1 8-9 (RM)	FS-RM-1803	Wildlife habitat - Black Hills	Rapid City, S. Dak.	II, D-1,3-a,3-b
FS 1 8-11 (NC)	FS-NC-1801	Conifer-aspen wildlife habitat - Lake States	St. Paul, Minnesota	II, D-3-a
FS 1 8-13 (NE)	FS-NE-1801	Wildlife habitat in northeastern forests	Warren, Pennsylvania	II, D-2
FS 1 8-15 (SE)(R)	FS-SE-1801(Rev.)	Forest wildlife habitat management in the Southeast	Asheville, N. C.	II, D-1,2,3-a
FS 1 8-16 (SO)	FS-SO-1801	Wildlife habitat in southern forests	Nacogdoches, Texas	II, D-1,2,3-a,3-c
		P. L. 480 PROJECTS		
	E21-FS-30	The quantity, quality, and seasonal variation of food resources available to red deer in various environmental conditions of forest management	Warsaw, Poland	

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CPO	FS			
		FOREST FIRE		
	FS-NOR-2101	Fire control systems	College, Alaska	III ---
	FS-PNW-2103	Forest fuels appraisal	Seattle, Washington	---
	FS-PNW-2104	Fire danger rating	Seattle, Washington	---
	FS-PSW-2102	Fire control planning	Riverside, California	III A, 5
	FS-PSW-2103	Fire chemistry	Berkeley, California	III A, 1
	FS-PSW-2104	Fuel break	Riverside, California	III A, 4
	FS-PSW-2105	Fire prevention	Berkeley, California	III A, 4
	FS-PSW-2106	Improvement of fire control methods	Riverside, California	III A, 5
	FS-PSW-2107	Fire behavior	Riverside, California	III A, 3
	FS-PSW-2108	Weather and topography	Riverside, California	III A, 2
	FS-INT-2101	Project skyfire	Missoula, Montana	III A, 2
	FS-INT-2102	Fire management	Missoula, Montana	III A, 3, 4
	FS-INT-2103	Fire physics	Missoula, Montana	III A, 1
	FS-INT-2106	Fire detection	Missoula, Montana	III A, 5
	FS-RM- 2101	Fire control	Fort Collins, Colorado	---
	FS-RM- 2102	Fire use	Flagstaff, Arizona	---
	FS-NC- 2101	Fire control systems	St. Paul, Minnesota	III A, 4
	FS-NC- 2102	Fire damage appraisal	Columbia, Missouri	---
	FS-SE- 2101	Fire use	Macon, Georgia	III A, 4
	FS-SE- 2102	Fire control	Macon, Georgia	III A, 5
	FS-SE- 2103	Fire meteorology	Macon, Georgia	III A, 2
	FS-SE- 2104	Fuel physics	Macon, Georgia	III A, 3
	FS-SE- 2105	Fire science	Macon, Georgia	---
	FS-SE- 2106P	Pioneering research project	Macon, Georgia	III A, 1
	FS-SO- 2102	Fire prevention	Alexandria, Louisiana	III A, 4

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CPO	FS			
		P. L. 480 PROJECTS		
E25-FS-13		Open fires and transport of fire brands	Madrid, Spain	
A10-FS-16		Pyrolysis of fuels in the presence of additives	Jerusalem, Israel	

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CPO	FS			
		FOREST INSECTS		
FS 2 2-1(NOR)	FS-NOR-2201	Forest insects, coastal forests	Juneau, Alaska	III, B-1-c, 4-b
	FS-NOR-2202	Biology, ecology and control of injurious forest insects in interior Alaska	Fairbanks, Alaska	--
FS 2 2-3(PNW)	FS-PNW-2201 (Rev)	Biology, ecology, and control of forest insects in the Pacific Northwest	Portland, Oregon	III, B-1-a,c, 4-a, e
FS 2 2-25(PNW)	FS-PNW-2203	Diseases of western forest insects	Corvallis, Oregon	III, B-1-c
	FS-PNW-2204(Rev)	Nutrition, behavior, and population dynamics of western forest insects	Portland, Oregon	III, B-4-d
FS 2 2-8(PSW)	FS-PSW-2201(Rev)	Biology, ecology, and control of forest insects in California and Hawaii	Berkeley, California	III, B-1-a, b, 2,3, 4-a, c, e, 6
FS 2 2-10(PSW)	FS-PSW-2203	Evaluation of chemical insecticides for control of forest insects	Berkeley, California	III, B-2
	FS-PSW-2204	Remote sensing and survey of the forest environment	Berkeley, California	III, B-6
FS 2 2-11(RM)	FS-RM-2201	Biology, ecology, and control of forest insects in the central Rocky Mountains	Ft. Collins, Colorado	III, B-4-a
FS 2 2-12(RM)	FS-RM-2202	Biology, ecology, and control of forest insects in the Southwest	Albuquerque, New Mexico	III, B-1-c
FS 2 2-13(INT)	FS-INT-2201(Rev)	Insect population dynamics	Ogden, Utah	III, B-6
FS 2 2-14(INT)	FS-INT-2202(Rev)	Biology of bark beetles	Missoula, Montana	III, B-3, 4-a
FS 2 2-15(INT)	FS-INT-2203(Rev)	Biology of defoliators and regeneration insects	Moscow, Idaho	III, B
FS 2 2-16(LS)	FS-NC-2201	Seed and cone, aspen, and shelterbelt insects	St. Paul, Minnesota	III, B-4-b, c, d, e

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		FOREST INSECTS		
FS 2 2-17(LS)	FS-NC-2202	Defoliators	St. Paul, Minnesota	III, B-1-c, 3
FS 2 2-18(LS)	FS-NC-2203	Plantation insects	East Lansing, Michigan	III, B-2, 3, 4-e
FS 2 2-22(NE)	FS-NE-2201	Insect biology	New Haven, Connecticut	III, B-1-c, 3, 4-b
FS 2 2-23(NE)	FS-NE-2202	Biotic control	New Haven, Connecticut	III, B-1-c
FS 2 2-24(NE)	FS-NE-2203	Chemical control	New Haven, Connecticut	---
FS 2 2-51(NE)	FS-NE-2204	Biology, ecology and silvicultural control of forest insects in the Northeastern States	Delaware, Ohio	III, B-2, 4-d
FS 2 2-49(NE)	FS-NE-2205 (Rev)	Biology and control of shade tree pests in the Northeastern States	Delaware, Ohio	III, B-1-a, 2, 3
FS 2 2-53(NE)	FS-NE-2206	Biological control; insect vectors of plant diseases	Delaware, Ohio	III, B-3, 4-b
FS 2 2-50(NE)	FS-NE-2207	Insect impact	New Haven, Connecticut	III, B-4
FS 2 2-25(SE)	FS-SE-2201	Bark beetles, defoliators, and sucking insects	Asheville, N. Carolina	III, B-1-a, 2, 4-b d, 6
FS 2 2-26(SE)	FS-SE-2202	Insect physiology	Durham, N. Carolina	III, B-2, 4-d
FS 2 2-27(SE)	FS-SE-2203	Insects of slash pine seed, plantations, and naval stores	Olustee, Florida	III, B-2, 4-c
FS 2 2-28(SE)	FS-SE-2204	Hardwood borers and pine insects	Athens, Georgia	III, B-1, 4-c, d, e
	FS-SE-2205	Biological control	Durham, N. Carolina	III, B-1-c, 4-d
	FS-SE-2206	Toxicology	Durham, N. Carolina	III, B-2
FS 2 2-31(SO)	FS-SO-2201	Wood products insects	Gulfport, Mississippi	III, B-5
FS 2 2-32(SO)	FS-SO-2202	Hardwood insects	Stoneville, Mississippi	III, B-2, 3
FS 2 2-30(SO)	FS-SO-2203	Pine insects	Alexandria, Louisiana	III, B-1-a, 2, 4-a, d

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CPO	FS			
		P.L. 480 PROJECTS - FOREST INSECTS		
A6-FS-4		Biological study of the more important insect pests attacking Pinus introduced from USA	Taiwan, China	III, B-4-d
A7-FS-6		Accelerated laboratory investigations on natural resistance of woods to termites	Dehra Dun, India	III, B-5
A7-FS-7		Survey for natural enemies of Chermes spp. attacking silver fir and spruce in the Himalayas	Bangalore, India	III, B-1-a
A7-FS-8		Survey of parasites for gypsy moth	Bangalore, India	III, B-4-b
A7-FS-25		Survey for natural enemies of Hypsipyla spp. in India	Bangalore, India	III, B-1-a
A7-FS-47		Studies on the population dynamics of the predators of Adelges spp. on silver fir and spruce in the Himalayas	Bangalore, India	---
A17-FS-1		Survey of insect fauna of the forests of Pakistan	Peshawar, West Pakistan	---
A17-FS-6		Studies on the natural enemies of insect pests of West Pakistan forests	Rawalpindi, Pakistan	III, B-1-a
A17-FS-9		Biology and ecology of important predators of spruce and fir aphids in Pakistan	Rawalpindi, Pakistan	III, B-1-a
E8-FS-38		Orienting stimuli guiding insect pests of forests to suitable host trees	Helsinki, Finland	III, B-4-a
E8-FS-63		Discovery and study of chemical substances in the bark of Pinus silvestris which are attractive to the bark beetle, Blastophagus piniperda L.	Helsinki, Finland	III, B-4-a

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CPO	FS			
E21-FS-2		Insects noxious to young stands of pine	Warsaw, Poland	III, B-4-e
E21-FS-3		Research on the growth and development and disease susceptibility of some species of trees from the U.S.A. to be planted in certain climatic regions of Poland	Warsaw, Poland	---
E21-FS-6		Investigations into the activity of the parasite, Trichogramma embryophagum (Hart) introduced into the forest environment with special attention to its capacity for spreading	Poznan, Poland	III, B-1-a
E21-FS-7		Studies in the development of improved strains of parasites of forest insects	Poznan, Poland	III, B-1-a
E21-FS-38		Studies on the ecology and biology of the more important parasites of Rhyacionia buoliana Schiff. in Poland	Warsaw, Poland	---
E25-FS-3		Pests of poplars and preventive and curative methods of control	Madrid, Spain	III, B-2
E25-FS-10		The study of parasites, predators and diseases of the gypsy moth and the possibility of their application in the biological control	Madrid, Spain	---
E30-FS-2		Study of the polyhedral virus disease of the gypsy moth	Zemun, Yugoslavia	III, B-1-c

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CPO	FS			
S3-FS-7		Disease and insect susceptibility and species adaptability of some North American pine species planted in Sao Paulo	Sao Paulo, Brazil	III, B-4-d
S5-FS-1		Disease and insect susceptibility and species adaptability of some North American forest tree species planted in Colombia	Medellin, Colombia	III, B-4-d
S9-FS-1		Disease and insect susceptibility and species adaptability of North American conifers planted in Uruguay	Montevideo, Uruguay	III, B-4-d
FS 2 2-36 (WO) (C)	FS-WO-2204 (C)	Isolation, identification and synthesis of pheromones of bark beetles	Menlo Park, California	III, B-4-a
FS 2 2-37 (WO) (Gr)	FS-WO-2205 (Gr)	Role of chemical messengers in the biology of western bark beetles	Berkeley, California	III, B-4-a
FS 2 2-38 (WO) (Gr)	FS-WO-2206 (Gr)	Induxing sexual sterility in the European pine shoot moth	Pullman, Washington	III, B-3
FS 2 2-39 (WO) (Gr)	FS-WO-2207 (Gr)	Nutritional and developmental requirements of the European pine shoot moth	Pullman, Washington	III, B-3
FS 2 2-40 (WO) (Gr)	FS-WO-2208 (Gr)	Population dynamics of the jack pine budworm	Ann Arbor, Michigan	III, B-4-b
FS 2 2-41 (WO) (Gr)	FS-WO-2209 (Gr)	Factors influencing the attraction, movement, and concentration of southern bark beetles	Durham, North Carolina	---

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FS 2 2-42 (WO)(Gr)	FS-WO-2210 (Gr)	Chemical investigation of host plant selection by the elm bark beetle	Columbus, Ohio	---
FS 2 2-43 (WO)(Gr)	FS-WO-2211 (Gr)	Investigations of the microflora of healthy and diseased gypsy moth	Storrs, Connecticut	---
FS 2 2-44 (WO)(Gr)	FS-WO-2212 (Gr)	Taxonomy of gamasid mites predatory on or associated with bark beetles attacking southern pines	Raleigh, N. Carolina	---
FS 2 2-45 (WO)(Gr)	FS-WO-2213 (Gr)	The biology and taxonomy of root aphids on conifers	Raleigh, N. Carolina	---
FS 2 2-46 (WO)(Gr)	FS-WO-2214 (Gr)	Basic studies on the nature and significance of diet and reproduction in Ips species bark beetles	Gainesville, Florida	---
FS 2 2-47 (WO)(Gr)	FS-WO-2215 (Gr)	Sex attraction and mating biology in insects, particularly sawflies	Madison, Wisconsin	---
FS 2 2-48 (WO)(Gr)	FS-WO-2216 (Gr)	The physical and chemical components of host plant resistance to the European pine shoot moth	East Lansing, Michigan	---

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Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS	FOREST DISEASE		
FS 2 3-1 (PNW)(R)	FS-PNW-2301 (R) Supersedes 2301 and 2304	Diseases reducing forest production	Corvallis, Oregon	III, C, 2-b
FS 2 3-2 (PNW)(R)	FS-PNW-2302 (R) Supersedes 2302 and 2303	Root diseases and soil microbiology	Corvallis, Oregon	III, C, 2-d, 2-e
FS 2 3-5 (PSW)(R)	FS-PSW-2301 (R) Supersedes 2301 and 2302	Diseases - California and Hawaii	Berkeley, California	III, C, 1-a, 1-c, 2-a, 2-c, 3-b, 3-e, 4-b, 7-a
FS 2 3-7 (INT)	FS-INT-2301	Native rusts of western conifers	Logan, Utah	III, C, 3-a
FS 2 3-8 (INT)	FS-INT-2302	Breeding western white pine resistant to blister rust	Moscow, Idaho	III, C, 3-b
FS 2 3-9 (INT)	FS-INT-2303	Diseases of western white pine and antibiotic action	Moscow, Idaho	III, C, 3-a, 3-b, 5-b, 7-a
FS 2 3-10 (RM) (R)	FS-RM-2301 (R) Supersedes 2301 in part	Diseases of trees and shrubs in the Central Rocky Mountains	Fort Collins, Colorado	III, C, 3-d, 3-e, 4-a, 6-a, 7-a
FS 2 3-11 (RM)	FS-RM-2302	Diseases of southwest ponderosa pine and associated species	Albuquerque, New Mexico	III, C, 1-c, 2-f, 3-g 4-e
FS 2 3-12 (NC)	FS-NC-2301	Diseases of northern conifers	St. Paul, Minnesota	III, C, 3-a, 3-d
FS 2 3-13 (NC)	FS-NC-2302	Diseases of aspen	St. Paul, Minnesota	III, C, 3-d
FS 2 3-14 (NC)	FS-NC-2303	Diseases of northern hardwoods	Marquette, Michigan	III, C, 3-g, 7-a
FS 2 3-15 (NE)	FS-NE-2303	Vascular and virus diseases	Delaware, Ohio	III, C, 5-a
FS 2 3-16 (NE)	FS-NE-2304	Cankers, heartrots, and physiogenic diseases	Delaware, Ohio	III, C, 2-a, 2-c, 3-d 3-g, 4-c, 6-e
FS 2 3-17 (NE)	FS-NE-2301	Mid-Atlantic tree diseases	Upper Darby, Pennsylvania	III, C, 3-d
FS 2 3-18 (NE)	FS-NE-2302	New England and New York tree diseases	West Haven, Connecticut	III, C, 3-d, 3-g

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CPO	FS			
FS 2 3-20 (SE) (R)	FS-SE-2302 (R)	Annosus root rot	Durham, N. Carolina	III, C, 2-a, 7-a
FS 2 3-21 (SE) (R)	FS-SE-2303 (R) Supersedes 2301 and 2303	Rusts, nursery and hardwood diseases	Asheville, North Carolina	III, C, 3-c
FS 2 3-22 (SE) (R)	FS-SE-2304 (R)	Soil-borne organisms	Athens, Georgia	III, C, 2-d, 2-e
FS 2 3-23 (SE)	FS-SE-2305	Air pollution	Asheville, North Carolina	III, C, 4-c
FS 2 3-24 (SO)	FS-SO-2301	Wood decay	New Orleans, Louisiana	III, C, 6-b 6-c
FS 2 3-25 (SO)	FS-SO-2303	Southern pine diseases	Gulfport, Mississippi	III, C, 1-c, 2-a, 3-c, 4-a, 5-b
FS 2 3-26 (SO)	FS-SO-2302	Bottomland hardwood diseases	Stoneville, Mississippi	III, C, 1-a, 2-e, 3-d, 3-g, 6-c
FS 2 3-27 (WO)	FS-WO-2301	Cultural characteristics of forest fungi	Laurel, Maryland	III, C, 2-e 6-c, 6-e
FS 2 3-28 (RM)	FS-RM-2303	Diseases of field windbreaks and nurseries in the Great Plains	Lincoln, Nebraska	III, C, 1-b, 4-b, 5-b
FS 2 3-29 (WO) (Gr)	FS-WO-2303 (Gr)	Aerobiology of piedmont forest fungi	Durham, N. Carolina	III, C, 2-a
FS 2 3-30 (WO) (Gr)	FS-WO-2302 (Gr)	Biochemistry of wood deterioration	Raleigh, N. Carolina	III, C, 3-g, 6-a
FS 2 3-31 (WO) (Gr)	FS-WO-2304 (Gr)	White pine blister rust resistance	Madison, Wisconsin	III, C, 3-b
FS 2 3-32 (WO) (Gr)	FS-WO-2305 (Gr)	Emzymic and nutritional studies of Cronartium fusiforme	Jackson, Mississippi	---

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CPO	FS			
FS 2 3-33 (WO) (Gr)	FS-WO-2306 (Gr)	Biology and biochemistry of root exudates	Ossining, New York	---
P. L. 480				
A6-FS-3		Important epidemic diseases of forest trees in Taiwan	Taipei, Taiwan	III, C, 1-a, 4-b, 4-e, 7-a
A7-FS-5		Accelerated laboratory investigations of durability of wood	Dehra Dun, India	III, C, 6-d
A7-FS-28		Biochemical studies of the Loranthaceae	Lucknow, India	III, C, 3-f
E15-FS-5		Biology and epidemiology of pine twist rust	Florance, Italy	III, C, 4-d
E21-FS-21		Forest tree seed disease organisms	Warsaw, Poland	III, C, 1-a
E21-FS-35		Saprophytic and semi-parasitic fungi as an environmental factor in the forest influencing the destructive activity of Armillaria mella and Fomes annosus	Poznan, Poland	III, C, 2-a
E21-FS-37		Occurrence and impact of diseases and insects of U.S. trees planted in certain regions of Poland	Warsaw, Poland	---
E30-FS-5		Susceptibility to diseases and and insects of selected North American forest tree species planted in Yugoslavia	Jastrebarsko, Yugoslavia	---

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CPO	FS			
S3-FS-7		Disease susceptibility of some North American tree species in Sao Paulo	Sao Paulo, Brazil	III, C, 1-d
S5-FS-1		Disease susceptibility of some North American tree species in Colombia	Medellin, Colombia	III, C, 1-d
S9-FS-1		Disease susceptibility of some North American tree species in Uruguay	Montevideo, Uruguay	III, C, 4-b

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Work and Line Project Number CPO	FS	Work and Line Project Titles	Work Locations	Line Projects Summary Index
		WOOD QUALITY RESEARCH		
FS 3 1-1 (FPL)	FS-FPL-3101	Wood structure and identification	Madison, Wis.	
FS 3 1-2 (FPL)	FS-FPL-3102	Fine wood structure	Madison, Wis.	
FS 3 1-3 (FPL)	FS-FPL-3103	Wood structure-wood property relations	Madison, Wis.	IV, A-2-b
FS 3 1-4 (FPL)	FS-FPL-3104	Environmental, growth, and silvicultural effects	Madison, Wis.	IV, A-2-b
FS 3 1-5 (FPL)	FS-FPL-3105	Wood quality evaluation and genetic effects	Madison, Wis.	IV, A-2-a
FS 3 1-6 (FPL)	FS-FPL-3106	Log and tree grade development	Madison, Wis.	
FS 3 1-7 (FPL)	FS-FPL-3107	Lumber quality yield development	Madison, Wis.	
FS 3 1-8 (FPL)	FS-FPL-3108	Sawmill improvement	Madison, Wis.	
FS 3 1-9 (PNW)	FS-PNW-3101	Douglas-fir (and associated species) log and tree grades	Portland, Ore.	
FS 3 1-10(PSW)	FS-PSW-3101	Western pine (and associated species) log and tree grades	Berkeley, Calif.	IV, A-2-d
FS 3 1-14 (WO) (GR)	FS-WO-3101 (GR)	Variation in the cell wall density of wood	New Haven, Conn.	
FS 3 1-11 (CS)	FS-CS-3101	Hardwood log and tree grades	Columbus, Ohio	
FS 3 1-12 (NE)	FS-NE-3101	Northern softwoods log and tree grades	Upper Darby, Pa.	
FS 3 1-13 (SE)	FS-SE-3101	Southern softwoods log and tree grades	Asheville, N. C.	
		SOLID WOOD PRODUCTS RESEARCH		
FS 3 2-1 (FPL)	FS-FPL-3201	Machining and veneer cutting	Madison, Wis.	
FS 3 2-2 (FPL)	FS-FPL-3202	Product and process development	Madison, Wis.	IV, A-5-2, A-5-b
FS 3 2-3 (FPL)	FS-FPL-3203	Wood drying	Madison, Wis.	
FS 3 2-4 (FPL)	FS-FPL-3204	Glues and gluing processes	Madison, Wis.	
FS 3 2-5 (FPL)	FS-FPL-3205	Glued wood products	Madison, Wis.	IV, A-4-c
FS 3 2-6 (FPL)	FS-FPL-3206	Wood finishing	Madison, Wis.	
FS 3 2-7 (FPL)	FS-FPL-3207	Fire performance of wood	Madison, Wis.	IV, A-4-a
FS 3 2-8 (FPL)	FS-FPL-3208	Environmental effects	Madison, Wis.	IV, A-4-b
FS 3 2-9 (FPL)	FS-FPL-3209	Preservative development and treating processes	Madison, Wis.	
FS 3 2-10(FPL)	FS-FPL-3210	Wood fungus and insects effects and control	Madison, Wis.	III, C-6-b, C-6-c
		WOOD FIBER PRODUCTS RESEARCH		
FS 3 3-1 (FPL)	FS-FPL-3301	Pulping process investigations	Madison, Wis.	IV, A-3-a
FS 3 3-2 (FPL)	FS-FPL-3302	Pulp properties	Madison, Wis.	
FS 3 3-3 (FPL)	FS-FPL-3303	Fiber processing	Madison, Wis.	
FS 3 3-4 (FPL) (R)	FS-FPL-3304 (Rev.) supersedes 3304 and 3305 in part	Papermaking and converting processes	Madison, Wis.	

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FS 3 3-6 (FPL)	FS-FPL-3306 supersedes 3305 in part	Fundamental properties of paper	Madison, Wis.	IV, A-3-c
		WOOD CHEMISTRY RESEARCH		
FS 3 4-1 (FPL)	FS-FPL-3401	Wood carbohydrates and conversion products	Madison, Wis.	IV, A-6-b
FS 3 4-2 (FPL)	FS-FPL-3402	Lignin structure and utilization	Madison, Wis.	IV, A-6-a
FS 3 4-3 (FPL)	FS-FPL-3403	Chemistry of wood and bark extractives	Madison, Wis.	
FS 3 4-4 (FPL)	FS-FPL-3404	Biochemistry of wood constituents	Madison, Wis.	IV, A-3-b
FS 3 4-5 (FPL)	FS-FPL-3405	Surface and polymer chemistry of wood	Madison, Wis.	IV, A-6-c
FS 3 4-6 (FPL)	FS-FPL-3406	Process development	Madison, Wis.	
FS 3 4-7 (FPL)	FS-FPL-3407	Analytical development, instrumentation, and service	Madison, Wis.	
FS 3 4-8 (WO) (GR)	FS-WO-3401 (GR)	The chemistry and ultra-structure of reaction wood	Syracuse, N. Y.	
FS 3 4-9 (WO) (GR)	FS-WO-3402 (GR)	Free radical studies of lignin related model compounds	Tucson, Ariz.	IV, A-6-a
FS-P-3	FS-P-3	Pioneering research in lignin chemistry	Madison, Wis.	IV, A-6-a
		WOOD ENGINEERING RESEARCH		
FS 3 5-1 (FPL)	FS-FPL-3501	Fundamental wood properties	Madison, Wis.	IV, A-1-a, A-2-a
FS 3 5-2 (FPL)	FS-FPL-3502	Properties of wood-base and related materials	Madison, Wis.	
FS 3 5-3 (FPL)	FS-FPL-3503	Analytical mechanics	Madison, Wis.	
FS 3 5-4 (FPL)	FS-FPL-3504	Research equipment and method development	Madison, Wis.	
FS 3 5-5 (FPL)	FS-FPL-3505	Design criteria	Madison, Wis.	IV, A-1-d, A-2-a
FS 3 5-6 (FPL)	FS-FPL-3506	Structural utilization	Madison, Wis.	IV, A-1-b, A-1-c
FS 3 5-7 (FPL)	FS-FPL-3507	Packaging	Madison, Wis.	IV, A-1-e
		REGIONAL UTILIZATION RESEARCH		
FS 3 6-1 (SE) (R)	FS-SE-3601 (Rev.) supersedes 3601, 3602 and 3603	Housing research, SE	Athens, Ga.	IV, A-1-c, A-2-a, A-4-b
FS 3 6-4 (CS)	FS-CS-3601	Utilization improvement, CS	Columbus, Ohio	
FS 3 6-5 (CS)	FS-CS-3602	Using Central States timber, CS	Carbondale, Ill.	
FS 3 6-6 (NE)	FS-NE-3601	Utilization improvement, NE	Upper Darby, Pa.	IV, A-3-b
FS 3 6-7 (ITF)	FS-ITF-3601	Timber utilization, Tropics, ITF	Rio Piedras, P.R.	
FS 3 6-8 (LS)	FS-LS-3601	Timber characterization and processing, LS	Duluth, Minn.	

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FS 3 6-9 (LS)	FS-LS-3602	Utilization improvement, LS	St. Paul, Minn.	
FS 3 6-11(PNW)	FS-PNW-3601	Utilization improvement, PNW	Seattle, Wash.	IV, A-2-a, A-4-c
FS 3 6-13(PSW)	FS-PSW-3601	Utilization improvement, PSW	Berkeley, Calif.	IV, A-2-a
FS 3 6-15(INT)	FS-INT-3601	Utilization improvement, INT	Missoula, Mont.	IV, A-2-a
FS 3 6-17 (RM)	FS-RM-3601	Utilization improvement, RM	Fort Collins, Colo.	IV, A-2-c
FS 3 6-19 (SO)	FS-SO-3601	Utilization improvement, SO	Alexandria, La.	IV, A-2-a, A-5-c
		FOREST ENGINEERING RESEARCH		
FS 3 7-1 (INT)	FS-INT-3701	Engineering systems for steep mountain forestry	Bozeman, Mont.	
FS 3 7-2 (LS)	FS-LS-3701	Engineering systems for northern hardwoods	Houghton, Mich.	
FS 3 7-3 (SO)	FS-SO-3701	Engineering systems for intensive forest management	Auburn, Ala.	
FS 3 7-4(PNW)	FS-PNW-3701	Engineering systems for heavy timber stands in the Pacific Northwest and Alaska	Seattle, Wash.	IV, B-2, B-3, B-4
FS 3 7-5 (NE)	FS-NE-3701	Engineering systems for Appalachian type forestry	Morgantown, W. Va.	IV, B-1
		P.L. 480 PROJECTS		
E8-FS-9[1/]		Factors affecting the impregnability of wood	Helsinki, Finland	IV, A-7-a
E8-FS-10[1/]		Moisture-temperature-time strength relations, etc.	Helsinki, Finland	
E8-FS-18[1/]		Accessibility studies of cellulose fiber	Helsinki, Finland	IV, A-7-a
E8-FS-39[1/]		Aerobic bacterial degradation of lignin	Helsinki, Finland	
S8-FS-1		Collection of wood samples, etc. from forest trees of Peru	Lima, Peru	IV, A-7-c
A17-FS-2		Investigation and evaluation of factors influencing the absorption, etc. in tropical timber	Sholashahar, Chittagong, E. Pakistan	
A17-FS-7		Collection of wood samples, etc. from trees in E. Pakistan	Sholashahar, Chittagong, E. Pakistan	
A7-FS-3		Working qualities of Indian timbers	Dehra Dun, India	IV, A-7-b
A7-FS-4		Studies of density and fiber characteristics of Indian timbers, etc.	Dehra Dun, India	
A7-FS-16		Cause and alleviation of refractoriness of hardwoods to seasoning	Dehra Dun, India	
A7-FS-27		Investigation of the phenolic constituents of certain woods and barks, etc.	Dehra Dun, India	IV, A-7-b

1/ Terminated during reporting period.

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CPO	FS			
FS 4 1	FS 4 1	FOREST SURVEY		V
FS 4 1-1 (NOR)	FS-NOR-4101	Forest Survey--NOR	Juneau, Alaska	V, A-1
FS 4 1-2 (PNW)	FS-PNW-4101	Forest Survey--PNW	Portland, Oregon	V, A-1
FS 4 1-3 (PNW)	FS-PNW-4102	Survey Techniques--PNW	Portland, Oregon	V, A-2
FS 4 1-4 (PSW)	FS-PSW-4101	Forest Survey--PSW	Berkeley, California	V, A-1
FS 4 1-5 (INT)	FS-INT-4101 [1]	Forest Survey-INT	Ogden, Utah	V, A-1
FS 4 1-6 (NC)	FS-NC-4101 [2]	Forest Survey--NC	St. Paul, Minnesota	V, A-1
FS 4 1-7 (NE)	FS-NE-4101 [2]	Forest Survey--NE	Upper Darby, Pennsylvania	V, A-1
FS 4 1-8 (SO)	FS-SO-4101	Forest Survey--SO	New Orleans, Louisiana	V, A-1
FS 4 1-9 (SE)	FS-SE-4101	Forest Survey--SE	Asheville, North Carolina	V, A-1
FS 4 1-10 (WO)	FS-WO-4101	Survey Techniques--WO	Washington, D. C.	V, A-2
FS 4 2	FS 4 2	FOREST ECONOMICS		V
FS 4 2-1 (PNW)	FS-PNW-4201	Production Economics--PNW	Portland, Oregon	V, B-3
FS 4 2-4 (PSW)	FS-PSW-4201	Production Economics--PSW	Berkeley, California	V, B-5
FS 4 2-5 (PSW)	FS-PSW-4202	Multiple-Use--PSW	Berkeley, California	V, B
FS 4 2-7 (INT)	FS-INT-4201	Production Economics--INT	Ogden, Utah	V, B
FS 4 2-8 (INT)	FS-INT-4202	Multiple-Use Economics--INT	Ogden, Utah	V, B
FS 4 2-9 (RM)	FS-RM-4201 [3]	Watershed Economics--RM	Flagstaff, Arizona	V, B
FS 4 2-11 (NC)	FS-NC-4201 [3]	Costs & Benefits of Forest Land Management--NC	St. Paul, Minnesota	V, B-2
FS 4 2-15 (SO)	FS-SO-4201	Production Economics--SO	New Orleans, Louisiana	V, B-6, 8
FS 4 2-18 (NE)	FS-NE-4201 [4]	Timber Production Economics--NE	Upper Darby, Pennsylvania	V, B-4
FS 4 2-13 (NE)	FS-NE-4201A [4]	Production Economics--CS	Columbus, Ohio	V, B
FS 4 2-19 (NE)	FS-NE-4202 [4]	Small Woodland Ownership--NE	Upper Darby, Pennsylvania	V, B
FS 4 2-14 (NE)	FS-NE-4202A [4]	Small Woodland Ownership--CS	Columbus, Ohio	V, B-7
FS 4 2-25 (WO)	FS-WO-4202	Forest Finance--WO	Washington, D. C.	V, B

[1] Supersedes FS-LS-4101 and in part FS-CS-4101.

[2] Including part of FS-CS-4101.

[3] Formerly FS-LS-4201.

[4] Formerly FS-CS-4201 and FS-CS 4202.

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CPO	FS			
FS 4 3	FS 4 3	FOREST PRODUCTS MARKETING		V
FS 4 3-1 (PNW)	FS-PNW-4301	Marketing--PNW	Portland, Oregon	V, C-8
FS 4 3-2 (PSW)	FS-PSW-4301	Marketing--PSW	Berkeley, California	V, C-2
FS 4 3-3 (INT)	FS-INT-4301	Marketing--INT	Missoula, Montana	V, C
FS 4 3-4 (RM)	FS-RM-4301	Marketing--RM	Fort Collins, Colorado	V, C
FS 4 3-5 (NC)	FS-NC-4301 5/	Marketing--NC	Duluth, Minnesota	V, C
FS 4 3-7 (NC)	FS-NC-4302 5/	Marketing Development--NC	Carbondale, Illinois	V, C-9
FS 4 3-6 (NE)	FS-NE-4303 6/	Marketing Practices--NE	Berea, Kentucky	V, C-3, 4
FS 4 3-10 (NE)	FS-NE-4302	Marketing Development--NE	Princeton, West Virginia	V, C-4, 6, 7
FS 4 3-11 (SE)(R)	FS-SE-4301(Rev.) 7/	Marketing--SE	Asheville, North Carolina	V, C-5
FS 4 3-13 (WO)	FS-WO-4301	Requirements--WO	Washington, D. C.	V, C-1
FS 4 3-12 (WO)(GR)	FS-WO-4302(GR)	Importance of Noise and its Potential Effect on Wood Use in Garden Apartments--WO	Ames, Iowa	V, C
		P. L. 480 PROJECTS (Forest Survey)		
E8-FS-32		Improved forest survey methods	Helsinki, Finland	V, A-6

5/ Formerly FS-LS-4301 and FS-CS-4302.

6/ Formerly FS-CS-4301.

7/ Supersedes FS-SO-4301 and FS-SE-4301.